A RAND NOTE

Methodologies for Planning On-Site and Aerial Inspections for Use in Treaty Negotiations

Maurice Eisenstein, Seth Weisberg, Ofra Stauber

RAND

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Prepared for the
Defense Nuclear Agency

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PREFACE

The objectives of this research were twofold: first, to develop analytical methods to assess the utility of cooperative verification methods for monitoring arms control agreements, and second, to apply those methods to support past U.S. negotiations for a treaty on Conventional Forces in Europe (CFE).

This work was meant to aid U.S. treaty planners and negotiators in assessing on-site inspection quota requirements while the negotiations were under way before the CFE Treaty was signed in November 1990. Since many facets of the final CFE Treaty, including site declarations, units of account, and site definitions, are now different, this Note will be of primary interest to readers concerned with inspection planning and strategies that incorporate aerial surveillance or "open skies" proposals, or with on-site inspection requirements for verifying adherence to other arms control measures. With modest modifications, the statistical techniques described here can be used to evaluate a variety of inspection regimes.

This study was conducted for the Defense Nuclear Agency within the Applied Science and Technology Program of RAND's National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense and the Joint Staff.

SUMMARY

This study has attempted to develop methodologies that would aid in establishing characteristics for an on-site and aerial inspection regime required to monitor compliance with the Conventional Forces in Europe (CFE) Treaty. Emphasis was placed on devising methodologies to establish monitoring requirements for NATO to validate data exchange with the former Warsaw Treaty Organization (WTO)[1] before ratification of the CFE Treaty, and on monitoring Soviet declared military sites after ratification and after the reductions in treaty limited equipment (TLE) take place. The study also considered methodologies for assessing aerial inspection regimes to detect sites suspected of being in circumvention of the CFE Treaty.

At the sponsor's request, this study was conducted on an unclassified basis. The study results therefore are based upon conceptual inspection regimes applied to a canonical population of declared Soviet military sites. It should also be noted that this study was completed prior to the conclusion of the CFE negotiations, and many differences exist in terminology and definitions of what constitutes an inspection, a site, etc. These differences do not, however, affect the utility of the methodologies described here.

A major objective of the CFE Treaty was to reduce the levels of NATO and WTO conventional forces, located in the region from the Atlantic Ocean to the Ural mountains (ATTU), to a lower and more stable level. A primary objective of the treaty was to ensure that the location and size of the respective forces precluded the launch of a ground attack without warning.[2]

Excess equipment on both sides are to be removed and destroyed over a period of three to five years. Further, the ATTU region is broken into four specific zones, with maximum TLE limitations for each zone defined for the period after the requisite destruction.

The maximum numbers of TLE within the ATTU, owned by any nation, are to be limited by treaty. Other constraints and confidence-building measures are also decreed by

[1]The WTO has been dissolved. Remaining NATO concerns for CFE Treaty verification will come from the former USSR. For the sake of simplicity, this Note refers to "the Soviet Union." Recent events in that area have moved quickly, and the military picture with respect to the newly independent republics and the Confederation of Independent States is unclear. The reader may consider "Soviet Union" to refer to an advanced military force from the region of the former Soviet Union.

[2]With the major political changes in Eastern Europe and the dissolution of the USSR, many of the original CFE Treaty objectives may be reached without the treaty.

treaty. Information will be exchanged on force readiness levels and on the command and control structure of declared forces.

This study did not consider data available from either National Technical Means (NTM) or Multinational Technical Means (MNTM) employing space-based sensors. From a U.S. perspective, aerial inspection as discussed in this study may not be the most cost-effective method of monitoring, or indeed necessary at all. Whether MNTM would satisfy all NATO participants in monitoring a CFE Treaty is also not known. With the breakup of the WTO and the demise of the Soviet Union, the requirements for monitoring a CFE Treaty may change significantly.

GENERAL FINDINGS AND CONCLUSIONS

There is likely no unique cost-effective answer as to how a CFE or any treaty-monitoring regime should be constructed. Any answer will be based on balances between competing political and military objectives, within political and economic constraints. On-site inspection (OSI) can be more thorough and less susceptible to deception than aerial inspection in detecting most treaty circumventions or infractions at declared military locations. Aerial inspections can overfly many sites per sortie, and thus can usually detect larger, more visible changes at declared sites than can OSI. Moreover, aerial inspections should increase the number of sites for which deception may have been implemented in a short period of time.

An important synergism between on-site and aerial inspections arises when an aerial inspection either quickly precedes or follows an on-site inspection. Such coordination, or its threat, could make deceptions of OSI more difficult to implement.

The success in monitoring a nation's adherence to TLE limits (detecting the deployment of a militarily significant quantity of TLE quickly) will hinge in part on whether there is comparable TLE at like battalions, regiments, etc., or, alternatively, on whether all TLE can be identified by serial number or by unique tagging. Regularity (comparable TLE) could be imposed by treaty, requiring that no site have more than a fixed number of TLE at any time. Alternatively, unique identification numbers or tags on TLE permit detection of illicit TLE by OSI.[3] Without either site TLE limits or unique TLE identification, hundreds more OSI may be required to accurately validate the exchange data or to detect militarily significant quantities (MSQ) of new TLE in a timely way.

[3]The CFE Treaty does not require TLE limits at sites, tagging, or TLE serial numbers to be provided.

The deployment of new MSQ of TLE at declared sites is more readily detected when the TLE is at only a few declared sites. Fewer OSI are needed to validate the exchange data, all other things being equal, when the TLE population is deployed at the smallest number of declared sites.

DATA EXCHANGE VALIDATION

To validate the initial exchange data base employing random stratified sampling methods, it is estimated that 200 to 250 NATO OSI will be required of the former Soviet sites, allowing for an estimate of the TLE population to within 1 percent of its actual value. This methodology, however, assumes a virtual stand down of TLE forces or individual TLE identification. Without TLE identification, and with great TLE irregularity among like units, nearly all the declared TLE sites may require inspection to ensure a 5 percent accuracy in the number of TLE in the former USSR ATTU region using simple random sampling methods. Moreover, the 200 to 250 OSI, using stratified sampling, will ensure, with high confidence, the detection of data exchange discrepancies if those discrepancies should exist at over 5 percent of an assumed 1200 declared in the former USSR sites. Data exchange discrepancies would consist of mislabeled units—calling a regiment a battalion, a tank regiment a motorized rifle regiment, a wrong command and control organization for a site, or a wrong level of site readiness.

The appropriate role for aerial inspection in the validation of data exchange is to image all declared units in the ATTU region of the former Soviet Union sites to verify that sites not inspected by OSI are what they are claimed to be and to provide a basis for comparison with future NATO aerial inspections. About 3 to 5 feet imaging resolution will be required to achieve these objectives. Depending on the sensor used to image declared sites and other operational details, 300 to 500 aerial inspection hours would be required to image 1200 Soviet declared sites located in Central Europe and in the ATTU region. If only 900 declared sites located in the former USSR are imaged, then 200 to 350 hours of aerial inspection are needed. The selection of a sensor for data base validation should reflect the objectives and requirements for aerial inspection in the post-ratification period.

RESIDUAL ERA MONITORING

Employing random stratified sampling methods requires 200 to 250 OSI annually at declared sites in the former USSR sites, along with 200 to 250 random aerial inspections to detect, with high confidence, the introduction of 1000 to 2000 additional TLE within a period of four to six weeks of their deployment. Moreover, if other than TLE number changes are occurring—changes in readiness levels, organizational command and control structure, or

TLE qualitative improvements—they may be detected with high confidence within eight weeks when 5 percent or more of the declared sites have undergone such changes.

Without TLE identification or site limits, and where TLE regularity is not ensured, the TLE monitoring becomes simple random sampling across the population to estimate the size of the TLE population. To detect with high confidence the introduction of 1000 to 2000 TLE within four to six weeks of their deployment at declared sites, when there is already great uncertainty and variability in the number of TLE deployed at those sites, may require that NATO perform at least 500 annual OSI.

If there is great variability in the number of TLE at declared sites and simple random sampling methods are employed, then 500 OSI annually may not be sufficient to detect increases of 1000 to 2000 TLE deployed at declared sites with any confidence for many months. Such irregularity could be an indication of difficulty and should raise concern.

Aerial inspections may have the potential for more readily detecting large newly deployed units at a few declared sites. Detecting new deployments of 1000 to 2000 TLE are predicated on the assumption that division-size deployments can be detected by aerial inspections with a high rate of inspections per sortie and an adequate number of sorties annually. As an example, with a range of 4000 miles per sortie and an average dwell time of 5 minutes to image a site, it is estimated based on Bernoulli trials that 100 to 125 annual sorties should with high confidence be able to detect at least one of five new divisions within four weeks in the ATTU region of the former USSR. If the average dwell time at a site increases to 15 minutes, the annual number of aerial inspections required to detect at least one of five new divisions will double, or, with 100 to 125 aerial inspections, take eight weeks to gain a high confidence for detection.

It is further estimated based on Bernoulli trials that approximately 300 annual aerial inspections would be required to detect at least one of five new divisions deployed at new or nondeclared sites within the European portion of the former Soviet Union within four weeks of their deployment, with high confidence. These results assume that a routine wide-area search by aircraft is undertaken throughout the former USSR west of the Ural mountains, employing a 10-ft resolution synthetic aperture radar (SAR) essentially unconstrained by weather and with a 4000 mile sortie range. It is also assumed that image processing and interpretation will be sufficiently automated to handle the large volume of imagery collected on each sortie to ensure the timely detection of nondeclared sites.

A nation could decide how many OSI and aerial inspections it wishes to make annually based on the rapid detection of a militarily significant treaty circumvention. Alternatively, the quota of inspections could be based on deterring wide-scale treaty violations and as a

confidence-building measure with less concern for detecting treaty violations with high confidence. The utility of monitoring to deter CFE Treaty violations is based on the premise of an unacceptably high political cost to being detected even if the likelihood of detection is not high.

RECOMMENDATIONS[4]

Because it is uncertain how organized and orderly OSI will be during the data exchange period, it is recommended that NATO be able to conduct between 500 and 1000 OSI to validate the data exchange. If there is ample cooperation between NATO members in accumulating and sharing consistent data to estimate TLE populations within a percent or two, and to validate other baseline data, fewer than the maximum number of inspections recommended would be necessary. It is to guard against uncertainty that between 500 to 1000 OSI be available to NATO for validating the baseline data exchange, and to ensure that an adequate fraction of the inspections can be performed by the United States.

It is recommended that all declared Soviet sites be inspected by air to validate the data for those sites not having OSI and to serve as a basis for comparing future aerial inspection imaging.

It is recommended that further consideration be given to a SAR with a resolution of between 3 and 5 ft for that purpose, recognizing that this could lead to a transfer of technology to the USSR. Having the capability to inspect by air almost anywhere, anytime in the ATTU region of the USSR could make a near-term SAR technology loss more acceptable. Moreover, a SAR with its all-weather capability could be the preferred sensor for aerial inspection in the post-baseline era, since many Soviet sites may be under continuous cloud cover for consecutive weeks or months.

It is recommended that in the residual monitoring post-baseline era that 450 to 500 annual OSI be permitted for all of NATO. This could ensure high-confidence detection of 1000 to 2000 tanks within four weeks of their being deployed among declared Soviet sites. It should allow the United States 100 to 125 annual inspections[5] to detect the deployment of 4000 new tanks to declared Soviet sites within six to eight weeks.

To ensure attaining these objectives, it is recommended that NATO annually perform 125 to 150 aerial inspections of declared sites in Soviet Europe, with the United States performing a subset of 50 to 60 aerial inspections annually. It is assumed that the aerial

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[4]These recommendations were made to OSD in early 1990, well before the CFE Treaty negotiations were concluded. They represent the utility of the methodology in this study to support ongoing negotiations.

[5]It is expected that 20 percent of all NATO inspections will be performed by the United States.

inspection sortie range will be between 1500 miles (with an average imaging dwell time at each site of 5 minutes or less) and about 4000 miles (with about 15 minutes average imaging dwell time per site or less).

If additional aerial sensors are eventually allowed, consideration should be given to employing infrared (IR) to increase the difficulties of ground deception.

A balanced monitoring regime should have the capability to detect new deployment of TLE at nondeclared sites. Using SAR with 10-ft resolution, between 40 and 75 annual aerial wide-area search sorties should give high confidence of detecting the deployment of 4000 TLE distributed over 10 or more nondeclared sites in Soviet Europe within four to eight weeks.[6] It may be possible to coordinate wide-area searches for suspect sites with the aerial inspection of declared sites.

The selection of SAR with 10-ft resolution for wide-area search is predicated on the proposed requirement to ensure that all areas of Soviet Europe are readily accessible for search. Otherwise, those areas of Soviet Europe that experience months of continuous cloud cover could become preferred locations for new TLE deployments.

Because TLE identification can assist in monitoring, the cost and feasibility should be found using individual TLE serial numbers to identify legally deployed TLE. Moreover, with individual TLE identification, compliance to population limits could devolve into counting TLE by military units rather than by individual TLE. Site inspections could still seek to find illicit TLE that are not properly identified.

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[6]Further investigation is needed to determine the need and requirements for automating the imagery processing.

ACKNOWLEDGMENTS

We are thankful to all those throughout the Defense Nuclear Agency and the Department of Defense who raised the questions that needed to be assessed and valiantly tried to keep RAND apprised of the ever-changing twists and turns of the CFE negotiations ongoing during this research.

Thanks must also be given to William Harris of RAND, who reviewed an early draft and who had many useful ideas on improvement of the Note. A very special thanks is owed Dr. John Adams of RAND, who helped formulate some of the underlying statistical approaches and also critically reviewed the results to ensure that an adequate sense of analytic rigor was maintained.

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1. INTRODUCTION

A primary objective of this research was to understand how well alternative inspection regimes might help to determine whether participating nations are in compliance with the Conventional Forces in Europe (CFE) Treaty. Another objective of the study was to develop an analytic framework within which to evaluate the capability and utility of alternative inspection modes.

At the sponsor's request, priority was given to employing the analytic methods to establish the numbers of on-site and aerial inspections necessary to adequately monitor the CFE Treaty. To some extent, this effort paralleled the Vienna negotiations, which at the time the study was completed were still under way, and thus many of the twists and turns of those negotiations may not be reflected here.

Two general monitoring approaches were pursued. The first is based on statistical sampling methods to estimate the population of treaty limited equipment (TLE) to determine whether treaty limits are being exceeded. The second approach is to randomly sample declared sites and determine whether those sites are in or out of compliance based on specific criteria. In either instance, the frequency of inspections was predicated on attaining a high confidence of detecting significant treaty violations, circumventions, or other force changes. Compliance is assumed if no violations or circumventions are uncovered or estimates of the TLE population size are within acceptable bounds.

The study was undertaken on an unclassified basis. The data used for illustrative purposes come from unclassified sources or were specifically developed for this analysis. In configuring various inspection regimes to determine their desirable characteristics and to assess their effectiveness, assumptions were made to facilitate the analyses. The number of Warsaw Treaty Organization (WTO) sites and their locations were based on unclassified sources.

The scope of the analysis, as depicted in Table 1.1, was limited to validation of the initial data exchange, monitoring of declared sites in the residual monitoring period after the initial conventional force and personnel are reduced, and detection of new suspect sites.[1]

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[1]We have defined new suspect sites as those undeclared sites suspected of containing TLE detected after treaty ratification.

Table 1.1

Scope of Study

Subject	Declared Sites	Known Suspect Sites	New Suspect Sites
Pre-ratification			
Validation data exchange	X		
Post-ratification			
Monitor TLE	X		
Monitor compliance	X		
Validate data update	X		
Monitor changes	X		X

Section 2 briefly describes the CFE Treaty negotiations, objectives, and aspects of the inspection protocol then under negotiation. It elaborates on the definition and numbers of TLE to be destroyed by each alliance. Possible adverse aspects of too intrusive monitoring of NATO military facilities are discussed.

Section 3 expands on the overall study approach, elaborating on the assumptions employed for analytic purposes and describing monitoring methods. Capabilities and requirements for aerial inspections are defined, and trade-offs between sensor performance and monitoring objectives are given.

Section 4 details an analytic infrastructure for determining the numbers of on-site and aerial inspections required to validate the initial data exchange. Illustrative examples, using an assumed WTO TLE distribution data base, are given.

Section 5 evaluates an inspection regime in the residual phase of the CFE Treaty, after excess TLE on both sides are eliminated or destroyed, to ensure treaty compliance. Again, assumed WTO TLE distributions demonstrate the use of the analytic framework.

Section 6 establishes an analytic framework for assessing the utility of aerial inspection to detect new suspect sites that may contain TLE or in other ways circumvent the CFE Treaty.

Section 7 integrates the analytic methods to describe how an overall inspection regime might be constructed and rationalized. Section 8 summarizes the study findings and sets forth some conclusions and recommendations.

No effort has been made to integrate National Technical Means (NTM) of the United States or of NATO allies with the CFE Treaty inspection regimes. Nonetheless, in Section 7 we draw some conclusions regarding the possible interaction of CFE inspection regimes and U.S. NTM.

In light of the political changes in Europe that were occurring at the time of this study, it was decided to pursue the monitoring requirements and inspection regimes that include treaty compliance by the former USSR. Ongoing political changes in Europe will affect the characteristics, if not the objectives, of a CFE monitoring regime. The results of this work may be used to evaluate other inspection regimes that reflect political changes.

2. BACKGROUND

The CFE Treaty signed in November 1990 between the NATO and WTO alliances was an outgrowth of the Conference on Security and Cooperation in Europe (CSCE). The CSCE mandated the CFE negotiations on force reductions. Fourteen NATO nations and seven WTO nations participated in these negotiations. Intra-NATO treaty positions were negotiated among delegates in Brussels and presented as a NATO position in Vienna.

Many political changes have occurred within and between the NATO and WTO alliances since this study began. After the CFE negotiations started, the Soviet Union announced the unilateral removal of some of its military units from Central Europe and the disbandment of others in the USSR. After the negotiations were completed, East and West Germany unified into one nation and the WTO nations withdrew from that alliance and the Soviet Union dissolved into independent republics. How these changes affect the achievement of the treaty objectives and ultimately the monitoring needed to verify compliance to the ratified treaty is not dealt with here.

A major objective of the CFE Treaty was to reduce the levels of NATO and WTO conventional forces in the region from the Atlantic Ocean to the Ural mountains of the USSR to a lower and more stable level.[1] It was also a primary objective of the treaty that the location and size of the respective alliance forces preclude the launch of ground attack without warning to the other side.

The treaty calls for reductions in TLE. Excess equipment on both sides are to be removed and destroyed over a period of three to five years. Further, the ATTU region is broken into four zones, with maximum TLE limitations for each zone defined for the period after the requisite TLE are destroyed. Table 2.1 shows the then-current holdings of TLE and the NATO and WTO agreement on proposed TLE reductions.

The maximum number of TLE owned by any nation in either alliance within the ATTU is defined by treaty. Other constraints and confidence-building measures are also decreed by treaty. Notification is required of military exercises employing forces above a given number and of the movement of TLE from storage sites or from their declared locations when above an agreed number. Other possible data sharing, for confidence-building purposes, could relate to the location of assault bridging equipment and its movement.

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[1]Richard Darilek and John Setear, *Arms Control Constraints for Conventional Forces in Europe*, RAND, N-3046-OSD, March 1990.

Table 2.1

NATO and WTO Conventional Arms and CFE Treaty Limits

Equipment	NATO	WTO	CFE Limit
Armored combat vehicle	30,100	51,000	30,000
Tanks	23,600	39,000	20,000
Artillery	18,500	42,000	20,000
Attack helicopters	2,300	3,500	2,000
Combat aircraft	5,900	10,000[a]	5,150[a]

SOURCE: *Boston Globe*, October 5, 1990, p. 1.
[a]Soviet only.

A major aspect of the CFE Treaty will be an inspection or treaty monitoring protocol allowing each side the right to inspect on-site, and possibly by air, the declared military sites of the other side. A protocol for using on-site and possibly aerial inspections to validate the initial data exchange was under negotiation. It is anticipated that after these negotiations are completed, each side will, within four months, seek to check the information and data exchanged on the numbers and location of the TLE of the other alliance. An important issue is how many on-site and aerial inspections are necessary and on what analytic basis could NATO estimate the actual number of former WTO TLE to a prescribed level of accuracy without having to inspect every declared site.

The inspection protocol will permit inspectors to validate the destruction of excess TLE at sites specifically declared for that purpose. For NATO, this could mean validating the destruction of nearly 100,000 WTO TLE. Specific guidelines defining destruction for each TLE type will be negotiated. At the start of the transition period when TLE is being destroyed, site monitoring and required notifications will begin to ensure treaty compliance. Monitoring will continue beyond the TLE destruction period and into a residual period for the duration of the treaty.

All 14 NATO nations were expected to participate in monitoring the WTO declared sites. The degree of participation of NATO countries in conducting inspections will be based upon the respective size of each member's ground forces in Europe. Inspection data will be shared among the alliance members and between alliances. NATO mechanisms were expected to be in place to coordinate the data sharing. Soviet and WTO compliance to the CFE Treaty will be assessed by each NATO member.

A treaty consultation commission will be established to mediate and discuss data exchange differences, possible treaty infractions, or outright violations. Presumably, most differences and misunderstandings regarding data exchange, TLE destruction, and general treaty compliance can be discussed and worked out within such a body.

In addition to the recent political changes noted above, there could be future political factors or differences within NATO that could influence the success of a CFE monitoring regime. NATO was not of one mind on how intrusive on-site inspections should be. Some NATO members, particularly the nuclear weapons states, believe that too intrusive inspections could compromise their national security interests. Others may be concerned about inspections that could reveal data on their TLE production to competitors or to other less friendly NATO members. There appears to be, however, an agreement among all participants to narrowly limit the use of inspection equipment, particularly for aerial inspections.

Sensors for aerial inspections are likely to be limited initially to one type of generally low resolution, or to older off-the-shelf technology. The United States and others are concerned about the prospects for technology transfer to the former USSR if advanced sensor equipment is employed. Agreements will allow each side to disassemble, nondestructively, the other side's aerial inspection sensors, to ascertain the mandated limited performance. The trade-off between effective monitoring with higher resolution sensors and technology transfer losses should be considered.

It is probably impossible to identify all the political considerations that could affect future CFE Treaty monitoring, but one or two possibilities are worth noting. It is not certain that all NATO nations will continue to have the same political interests and objectives over the ensuing years, particularly in light of the WTO and USSR dissolution. Some may see CFE verification as unnecessary or contrary to their political interests.

Alternatively, continuing political changes in the aftermath of the dissolution of the USSR could lead to monitoring difficulties. When a Soviet republic secedes from the USSR, will declared facilities in that republic be available for future inspection? Will future conflagrations, big or small, within the borders of the old USSR preclude inspection in a republic or region for a period of time? Will such conflagrations require the movement of TLE in violation of treaty zone limitations? These and other issues could well affect the prospects for effectively monitoring a CFE treaty.

To identify or predict what future CFE monitoring problems might be, we may learn from past treaties to which NATO and then-WTO members were signatories. Most recently the Intermediate-range Nuclear Force (INF) Treaty allowed for on-site inspections of U.S. and Soviet sites used for production, testing, and deployment. Also, the CSCE agreement has allowed NATO and WTO inspectors to witness each other's military exercises with troop

sizes above some minimal level.[2] Not all of these experiences have been positive ones, but they do offer a basis upon which to build a CFE on-site inspection regime.

NTM, and potentially Multinational Technical Means (MNTM), will be required to monitor regions not included in the CFE Treaty where conventional and nuclear forces of the former Soviet Union will be located, and to monitor important events and activities around the globe. Whether aerial inspections will be required will be a function of what level of confidence is needed to monitor a treaty, the level of cooperation between nations, and whether any additional information and data needed can be provided more cost-effectively by NTM or MNTM.

[2]Robert G. Gough, *The Conduct of On-Site Inspections: Lessons Learned from Inspections and Practice Inspections,* Sandia National Laboratory, Verification Systems and Technology Division 9241, July 1988.

3. STUDY APPROACH, DEFINITION, AND METHODS

OVERALL ANALYSIS FRAMEWORK

We have used an analytical framework to size inspection regimes as a function of the monitoring objectives and level of confidence desired in determining whether the monitoring results indicate treaty compliance or a significant degree of noncompliance.

In principle, if no violations are found during an ongoing inspection process, two statements may be simultaneously true: (1) at a given level of statistical confidence the inspected party is in compliance with the treaty and (2) with the same level of confidence, the magnitude of any treaty circumventions, should they exist, are less than some prescribed level. Basically, the inspection process is envisioned as being a series, over time, of on-site or aerial inspections at randomly selected declared military sites of the inspected party.

Important to this approach is a clear definition of what degree of noncompliance is judged to be significant. In strategic arms control treaties, the significance of even one additional nuclear weapon can be great. In dealing with conventional force limits, overall infractions may appear politically significant, but in military terms may be insignificant if the infraction is an isolated incident. A large number of small infractions, however, could, in principle, be important militarily. We do not define what is or is not militarily or politically significant, but rather note that an understanding of these issues is essential and that an inspection or monitoring regime can, in principle, be devised to ensure the timely detection of militarily significant treaty violations.

What is considered militarily significant can change as political conditions change. Indeed, what was believed to be a militarily significant increment of WTO or Soviet forces in Europe when the treaty was being negotiated may have changed since the political earthquake that fragmented the Warsaw Pact and the Soviet Union. What in the future may be considered militarily significant changes to the follow-on to the WTO or Soviet forces will reflect the future level and state of readiness of NATO military forces.

In subsequent sections assumptions are made, for illustrative purposes, as to what could be militarily significant in terms of excess of TLE limits and in terms of treaty infractions.

The CFE monitoring regime can be a confidence-building measure (CBM). By each side monitoring the other, each side will have greater assurance that the other is not preparing to launch a conventional strike. The importance and utility of CFE monitoring as

a CBM, however, will depend on many factors, but especially on the political environment in Europe. What may be important to track to build confidence are qualitative improvements to the numerically controlled forces and increases in frequency and intensity of military maneuvers and exercises that are not required by the treaty to be reported. The monitoring regime should be able to detect and track, in a timely manner, the deployment of new improved TLE or changes in exercise frequency.

To implement these CFE monitoring regimes, algorithms can be designed to estimate the number of inspections required to achieve a probability of detecting one or another militarily significant treaty violation, or other change, at the declared sites or elsewhere, within a specific period of time, as a function of how widespread and observable or detectable the change or violation is.

MECHANISMS FOR MONITORING

A primary method for monitoring the CFE Treaty will be on-site inspection (OSI).[1] OSI will be used to validate the data base exchange during a four-month period prior to treaty ratification. The size of the inspection teams, and the details of when they announce which sites they will inspect, are specified in the CFE inspection protocol. A six-hour pre-notification of a site inspection may be agreed to by treaty. Teams that are inspecting one site may on subsequent days inspect other sites in that region. Past information on the INF Treaty suggests that most site or facility inspections can be completed within 24 hours.

The monitoring protocol assumes a degree of cooperation between inspecting and inspected party. What precisely this implies and under what circumstances is unclear. In the extreme, cooperation could lead to a temporary stand down of TLE forces to allow for their accurate counting at declared sites. Alternatively, cooperation may take the form of generally unobstructed inspection of on-site locations and facilities, reasonable access to TLE for accounting, and the availability of other site-specific data prescribed by the treaty. It is possible but uncertain that TLE serial numbers can be made available to uniquely distinguish each TLE.[2] TLE serial numbers would improve the ability of the inspecting party to count TLE and to detect TLE limit circumventions. An important issue is what impact a lack of cooperation or deceptive actions to confuse inspectors will have upon achieving monitoring goals.

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[1]For a more elaborate discussion on CFE Treaty verification and monitoring methods, see Volker Kunzendorff, *Verification in Conventional Arms Control,* IISS, Adelphi Paper 245, Winter 1989.

[2]For a useful discussion on the utility of TLE serial numbers in monitoring arms control treaties, see W. R. Harris, *Statistical Challenges in the Design and Verification of Arms Control Treaties,* American Statistical Association, Anaheim, CA, August 1990.

After the CFE Treaty is ratified, each side will pursue the removal and destruction of excess TLE at declared destruction sites. Each side will monitor the destruction of the other's TLE. It is anticipated that inspection teams will be located on a continuing, or routine, basis at the destruction sites to validate the TLE destruction.

After the CFE Treaty is ratified, routine inspections will be undertaken to monitor the TLE levels within zones, activities as prescribed by treaty, and activities not prescribed by treaty but considered as important CBMs. Equipment used by OSI teams will consist of TLE descriptive materials, cameras, or other equipment to document alleged data discrepancies or infractions, and communications gear to reach their respective leadership, on and off site.

Sensitive on-site locations will be off bounds to the OSI team, but in special instances efforts are to be made by the inspected party to ensure compliance at those locations to the inspecting party's satisfaction.

In addition to routine inspections of declared sites, negotiations may allow challenge inspections of nondeclared suspect sites. If the suspect site is a sensitive one, the inspected party may use other means to assure the inspecting party that the site is not illegally harboring TLE or is not in violation of the treaty. Challenge OSI of paramilitary and other suspect sites may be requested to determine there is no illegal TLE.

There are several important questions regarding OSI that need to be answered before designing an inspection regime. First, what should the political and military objectives be for OSI monitoring? How effective and timely must uncovering of military or politically significant violations or changes be? How many routine or challenge inspections should each side be able to perform annually? The answers to these and other questions will be related to how well an OSI team can count TLE, and how well they can detect other quantitative and qualitative circumventions or infractions. Some of these questions are addressed below.

Another important mechanism for monitoring CFE Treaty compliance could be aerial inspection. Negotiations are continuing on how to implement an aerial inspection regime for CFE.

It is uncertain whether aircraft owned by the inspecting or inspected party will be allowed to overfly the inspected party's territory; whether photographic, infrared (IR), or radar systems will be used to image declared sites; and whether imaging will be allowed away from declared sites to locate new suspect sites. The altitude of flight, the duration of flight (time for imaging), and the annual number and rate of such flights are yet to be established.

OSI may allow for the viewing and recording of TLE and other site characteristics at close range. Aerial inspection will first have to image a site and then have the imaging

reviewed by interpreters seeking evidence of treaty violations. The aerial inspection film or tape will be shared with the inspected party and processing may have to occur within the country of the inspected site. The utility of aerial inspection as a means of monitoring will, inter alia, depend on the type of sensor used, sensor resolution, and the warning time of pending aerial inspection of a specific site. The utility of aerial inspection will also depend on how much flight time or coverage is allowed.

Photo imaging will be limited to daytime and generally clear weather, IR imaging will be limited primarily by cloudy weather. Imaging by synthetic aperture radar may not be limited by these conditions. The level of sensor sophistication used in aerial inspections may be limited by concerns for advanced sensor technology transfer to the former USSR.

Because that aerial inspection imaging may be resolution-limited when using radar or weather-limited with either photo or IR imaging, it is important to decide what objectives are best served by aerial inspection if only one sensor type is allowed.

An option is to use aerial inspection to locate the declared sites and to validate the data exchange and what type sites they really are. Another option would be to overfly declared sites on a routine basis to detect relatively "large" changes that could indicate the introduction of additional units, preparation for introducing new units, or new airstrips or aircraft protective revetments, and the like. It is unlikely that aerial inspections could be used for TLE counting unless high-resolution sensors were used and the inspected party cooperated by placing TLE in open unobstructed areas. An exception may be the detection of TLE movements, of some minimum size, from sites where they were stored in the open.

Alternatively, aerial inspection may be used in a wide-area search mode to detect new suspect sites. The question of which imaging sensor to use will hinge on trade-offs between sensors with a wide field of view (photography) but limited to daytime and clear weather flights, and an all-weather day or night radar system with limited resolution.

From the U.S. vantage point, the selection of an imaging sensor for aerial inspection may hinge on how much data it adds to that collected by National Technical Means. Other NATO nations may have another preference for an aerial inspection sensor given their more limited ability to collect data on Russian and other former Soviet republics' military capabilities and deployments.

MONITORING DISCRIMINANTS

In developing an analytic framework in which to evaluate inspection regimes, it will be important to understand how well inspections, on-site or by air, can count TLE, ascertain whether operational changes have occurred at a declared site, determine if TLE equipment

has been improved, or determine if the number of troops deployed at a site has increased or decreased. (There is an underlying assumption here that even with information supplied by the inspected party, the inspecting party will seek the independent capability to discern qualitative and quantitative changes at declared sites, irrespective of whether they are treaty limited.)

This study did not find what the prospective discriminants of change are or the probability—even without deception—they would be observed and identified as changes or violations.

Quantitative changes are more likely to be visible and identifiable. Thus, numbers of TLE at an inspected site, or the number of buildings or garages at a site, should be readily discernable.[3] Detecting qualitative changes, such as changes in levels of readiness or site activity, may require experts on military operations to be part of the inspection team.

To deal with this issue within the analytic framework developed here, the probability of identifying a change or violation at a visited site, P_i, is included as a variable. (Realistic assessments of P_i for various kinds of site changes will require a separate study.) Table 3.1 lists some of the events for which quantitative and qualitative discriminants need to be defined. The discriminants and their likelihood of being detected may differ between OSI and aerial inspections.

It has been generally assumed that the political decision that an infraction or violation or military change has occurred, based on OSI or on aerial inspection (AI) data, will be made less than a day after the data are acquired. This leads to further assumptions regarding the

Table 3.1

Residual Monitoring Inspection Observables

Observable	Appropriate Inspection Regime
Increased TLE	OSI and AI
TLE movement from storage	OSI or AI
Changes in levels of readiness	OSI or AI
Equipment upgrade	OSI
Unit connectivity; C^2	OSI
Changes in activity levels	OSI or AI
Size and frequency of exercises	AI
New sites and facility construction	OSI or AI
Formation of new units	AI

[3]There may be exceptions to this assumption in large sensitive areas where inspections are not permitted. An example may be the underground caves and tunnels constructed by the Germans in World War II to hide and protect production and storage of military equipment and armaments.

rapidity with which imaging data can be processed and reviewed. For data obtained from OSI, this may be a reasonable assumption. For aerial inspection of declared sites, where a few hundred images per sortie are collected, it may also be reasonable to assume a 24-hour review. For wide-area search for new undeclared and suspect sites, many thousands of images will be accumulated per sortie. The prospect of those images being reviewed within 24 hours would be slim unless automated.

GENERAL ASSUMPTIONS AND DEFINITIONS

A declared military site contains one or more garrisons. For the purposes of this study, we have defined a military garrison as a basic military unit, containing, for ground forces, a battalion, a regiment, a brigade, or a division, and for air forces, a squad or a wing. (See Figure 3.1.) We have also assumed that only one inspection would be charged for each site visited, and that all garrisons at that site would be inspected during one inspection.[4] We have counted in this study a single sortie as one aerial inspection irrespective of how many sites it overflies and images.

To illustrate how the analytic framework is used, a distribution of former WTO and Soviet declared land and air bases has been assumed; see Table 3.2. We have assumed a distribution of sites as they may exist today and as they may be in three years after the CFE Treaty is ratified and forces are reduced to treaty-mandated levels. The assumed number of declared Soviet sites containing TLE drops to 500 from 750 in the three years after ratification, representing the withdrawal of Soviet forces from other WTO countries.

We have also assumed that the Soviet declared sites within the former USSR are uniformly distributed in an area bounded by the Ural mountains on the east and the western border, an area of over 2 million square miles.[5] This allows the average distances and flight times between sites for aerial inspections to be calculated.

We have assumed that declared Soviet sites will equal or exceed in size and area that of their declared garrisons, unlike NATO declared sites which are primarily garrisons of individual units. For air bases, we make no distinction among sites, garrisons, and military units.

ALTERNATIVE STATISTICAL APPROACHES AND STRATEGIES

Various probabilistic and statistical methods can be applied to estimate TLE numbers, to detect treaty circumventions, or to show that the inspected party is in compliance with the

[4]The CFE Treaty counts each OSI of a garrison as one inspection.

[5]About half of this area is contained within the new Russian republic.

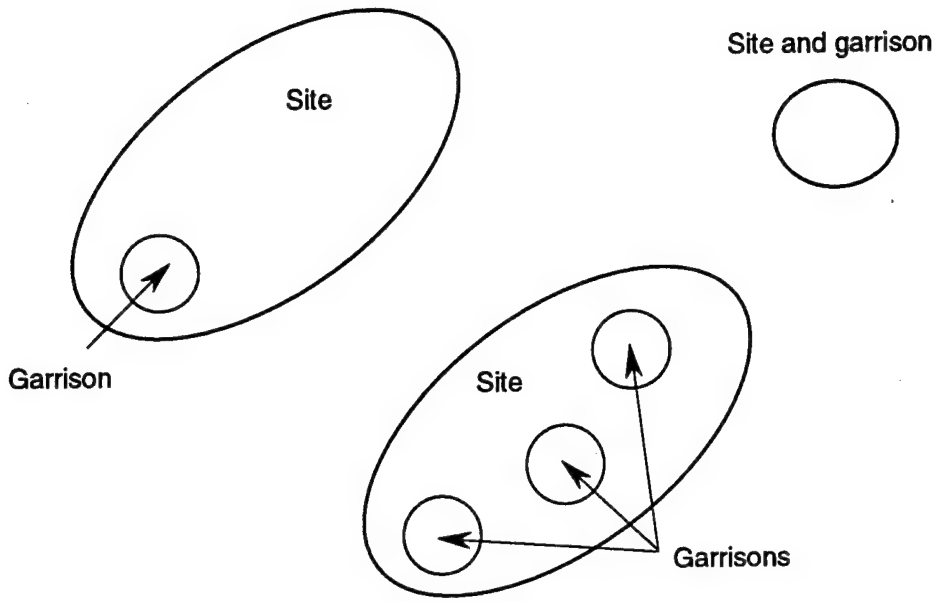

Figure 3.1—Declared Military Site: Definitions

Table 3.2

Inspection Domain Assumed Distribution

Declared Unit	Pre-ratification WTO	Pre-ratification USSR	Post-ratification + Three Years USSR
Site			
Ground	1500	900	650
Air base	500	300	250
	2000	1200	900[a]
Garrison[b]			
Ground	2000	1500	950
Air base	500	300	250
	2500	1800	1200
TLE site		750	500

[a]Assumed uniformly distributed over former USSR.
[b]Garrison is a regiment or smaller independent unit.

treaty-mandated limits and requirements. A number of statistical sampling approaches are listed in Table 3.3, some of which are used in this study. A basic issue is the cost for implementing on-site and aerial inspections and how those costs will be affected by one inspection strategy versus another.

A simple, and perhaps least-cost, sampling strategy would be to select sites to be inspected months before the inspections are to be performed, allowing ample time to plan, prepare, and coordinate those inspections. The majority of sites could be selected randomly or on a priority based on intelligence information. Perhaps the most costly approach would be to withhold the site selections until a few days before the inspections, to maximize data return from the most recent inspections. Reasons for wanting to wait to decide what sites to inspect may be a desire to change inspection strategy or to focus inspections on certain classes of military units or at certain locations within the inspected country.

There are uncertainties as to how well an inspection regime will work when applied to a large and dispersed number of locations as was the case in the USSR. Uncertainties in cooperation by the inspected nation, or in the interest and coordination among the inspecting nations to collect and share data, can influence the utility of one or another approach.

Statistical approaches have underlying assumptions that may not always be met in the operational world. It is likely, then, that the inspection regime will adjust for these assumptions and evolve and develop as a function of the interest and experience of the participating nations. The experiences of monitoring CFE should play an important part in devising a monitoring regime for a CFE II if it should ever come about.

Table 3.3

OSI Sampling Strategies

- Maximum number of units visited
- Random or uniform sampling
- Stratified sampling
- Weighted sampling
- Sequential sampling
- Mixed sampling strategies

4. DATA EXCHANGE VALIDATION

ISSUES FOR CONSIDERATION

In this section, we develop an analytic framework to help determine how extensive an OSI and aerial inspection regime should be to adequately validate the data exchange between NATO and the WTO alliances prior to the CFE Treaty ratification. Specifically, we examine the question of validating data at declared military sites. The question of whether specific WTO sites should be declared is not addressed here.

The validation issues that were considered are:

- How accurate should the estimation of declared number of TLE and other exchange data be?
- How many OSI are needed to accurately estimate the number of TLE and to validate other exchange data?
- How might aerial inspection be used to validate the data exchange and how many annual aerial sorties are desirable?
- How can cooperation or lack of cooperation between parties affect the amount of OSI and aerial inspection needed?
- How extensive a role should the United States have in the validation inspection process, that is, what percentage of the OSI and aerial inspections should the United States perform?

The degree of desired accuracy in the data validation process will be based upon political, military, and economic considerations. We would expect, however, that with the many tens of thousands of TLE in both alliances it would not be unusual if a small fraction of the TLE were either misplaced or unaccounted for. Thus, we do not envision the need for an inspection regime that is geared to detect small or likely transient errors in the data exchange. Generally, the greater the accuracy desired in estimating TLE, the more inspections required.

ON-SITE INSPECTION SAMPLING

One approach to validating the exchange data would be to inspect each and every WTO site. With the political changes in the WTO countries at the time of this study, it was judged that visiting only Soviet sites would be sufficient. That decision is a political one.

Another approach would be to visit a sample number of sites, chosen on the basis of their importance, but also with randomness, to give assurances, at some level of confidence, that the sample findings are representative of the TLE population. Aerial inspections could validate site location and identify the type of units at declared sites that had no OSI, and to image all declared sites prior to treaty ratification. Pre-ratification imaging would provide a basis for comparing post-ratification imaging of those sites.

There are two major objectives for exchange data validation. The first is to validate the actual numbers of declared TLE and their locations. A second objective is to ensure that other information in the data exchange is reasonably accurate. The TLE count requires visiting a sufficient and representative number of TLE sites. To ensure the accuracy of other exchange data, an adequate sample of all sites will be required. (Other exchange data include unit types and locations, declared readiness levels, command and control connectivity, etc.)

To illustrate the method for determining the number of OSI needed to estimate the total TLE quantity[1] at declared sites, an assumed distribution of declared Soviet tanks and tanks sites is given; see Table 4.1. Table 4.2 gives an assumed distribution for declared Soviet military aircraft among Soviet air bases. The distributions are defined by type of unit, the total number of TLE at all the sites of a unit type, the average number of TLE per unit type (μ_U), and the standard deviation of the numbers of TLE among unit types (σ_U). Totals for the entire TLE population are also given, as are the μ_p and σ_p for the entire assumed TLE population.

If the TLE distribution at the declared sites and the variations among those sites are as described in Tables 4.1 and 4.2, with a high degree of TLE unit regularity during the validation period, then proportionate stratified random sampling techniques[2] can be employed to estimate the total TLE population size. If, however, there is little regularity among comparable type units (regiments, battalions, wings, etc.), then the standard deviations shown in Tables 4.1 and 4.2 for each unit type will no longer pertain. As the standard deviations increase for unit types, so will the number of OSI required to achieve a desired level of accuracy for estimating the TLE. At some point the standard deviation can increase to a point where stratified sampling may no longer be an efficient sampling process, and less efficient statistical estimation processes may be required.[3]

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[1]The TLE population estimate is derived from multiplying the estimated average number of TLE over all sites, x, by the total number of TLE sites, where x is assumed to be normally distributed.

[2]See Appendix A, part B.

[3]There are many texts describing stratified sampling techniques. Of special usefulness is William G. Cochran, *Sampling Techniques*, Third Edition, John Wiley and Sons, New York, 1977.

Table 4.1

Data Exchange Validation Assumed Tank Distribution (USSR: ATTU Only)

Unit type	No. of Sites	No. of Aircraft	μ_t	σ_t
Battalion	75	2625	35.0	3.50
Light regiment	120	9600	80.0	5.29
Regiment +	30	3600	120.0	6.48
Light division	60	10800	180.0	7.94
Division	30	9000	300.0	10.25
Other	60	375	6.25	1.48
Total	375	36000	$\mu_p = 96$	$\sigma_p = 81.4$

Table 4.2

Data Validation Assumed Treaty-Limited Aircraft Distribution (USSR: ATTU Only)

Unit type	No. of Sites	No. of Aircraft	μ_t	σ_t
Squad	100	1500	15	1.50
Light wing	50	1250	25	1.94
Wing	50	2250	45	2.60
Heavy wing	50	3250	65	3.12
Repair facility	50	250	5	0.87
Total	300	8500	$\mu = 28.3$	$\sigma_p = 20.5$

To indicate how TLE deployment regularity or irregularity affects OSI sampling, Figure 4.1 gives the number of on-site inspections needed, as a function of an increasing population σ_p value, to estimate within ε percent the population of tanks to a desired level of accuracy and with a desired confidence level. If the TLE variation or standard deviation among Soviet sites is relatively large, or there is little a priori information as to where the tanks are located among the declared sites, the numbers of inspections will increase.

Figures 4.2 and 4.3 give, as a function of desired TLE estimation accuracy and level of confidence, the least numbers of OSI needed to estimate the size of the tank and aircraft populations, given there is a high degree of TLE regularity among sites or a near TLE stand down during the validation period, and proportionate stratified sampling[4] is used. Also shown is a worst case for the number of OSI needed where little a priori information on the location of the TLE is available and random sampling[5] of the TLE site population is necessary.

[4]See Appendix A, part B.
[5]See Appendix A, part A.

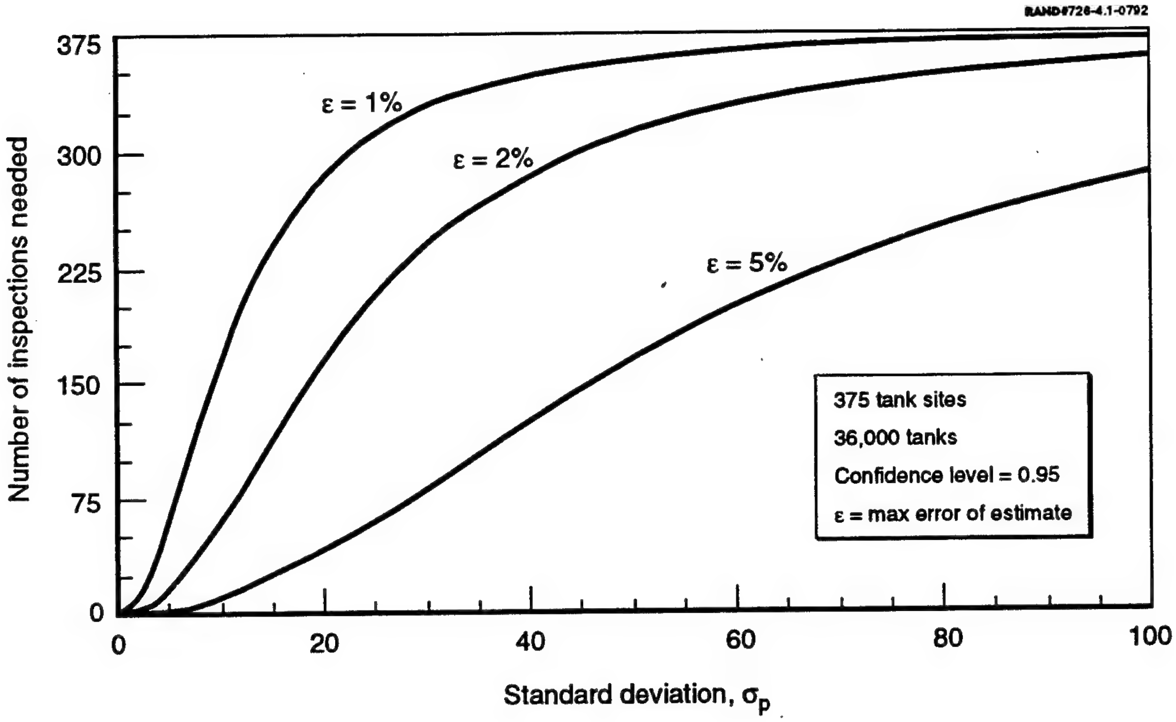

Figure 4.1—OSI Validation of Tank Numbers: Random Sampling

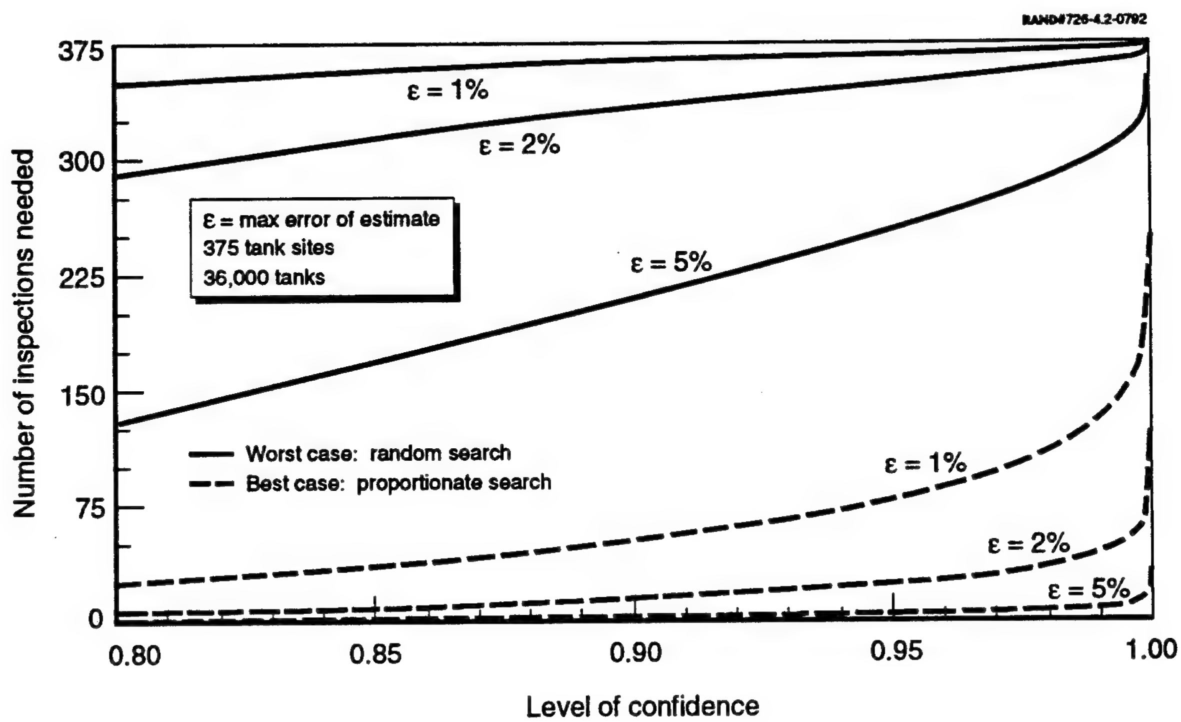

Figure 4.2—OSI Visits Needed to Estimate Tank Numbers

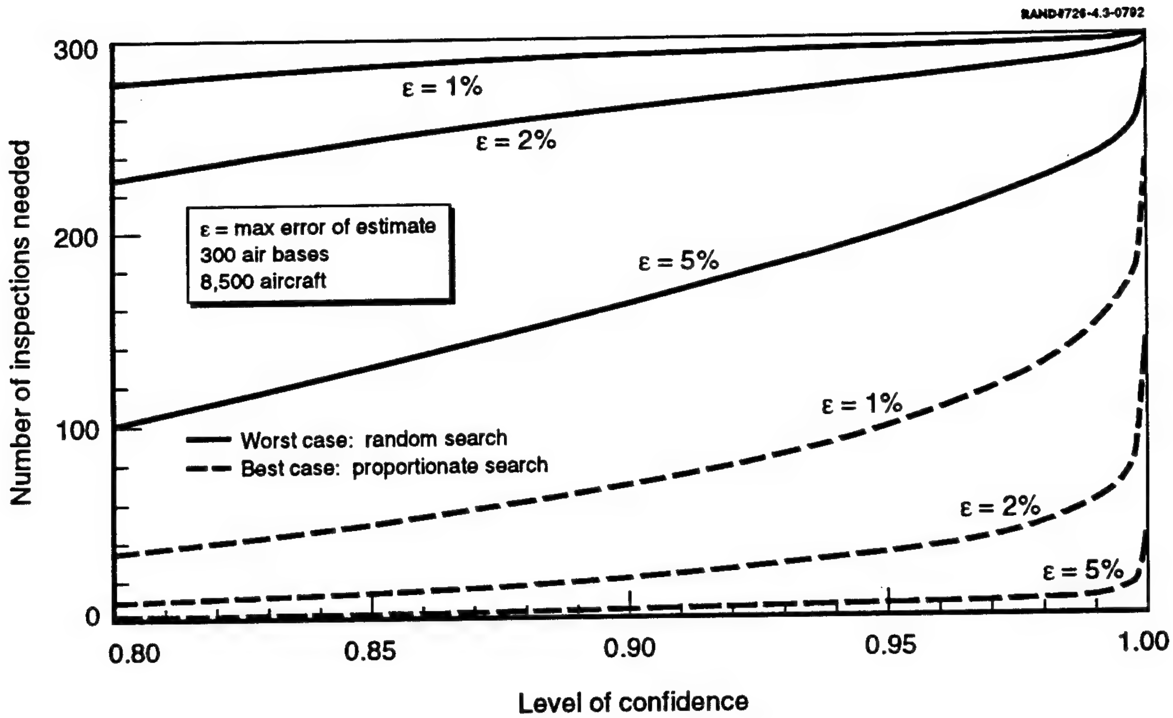

Figure 4.3—OSI Visits Needed to Estimate Number of TLE Aircraft

Figures 4.2 and 4.3 demonstrate that, without a high degree of regularity or a near stand down of the TLE, large numbers or almost all of the TLE sites may have to be inspected to obtain a TLE estimation accuracy of one or two percent. Conversely, if the number of inspections is predicated on assumptions of regularity or small TLE variations per site, but that is not the case, there will be large uncertainties in the estimated number of TLE.

In addition to validating TLE populations, there is also the desire to determine that other, perhaps less quantitative data exchange information is essentially correct. Here the statistical sampling process will be based on the assurance of finding incorrect data when the number of sites with incorrect data exceeds a prescribed threshold. Incorrect data consist of describing a declared unit erroneously (e.g., labeling a tank regiment a motorized rifle regiment, or misidentifying the division command of a declared regiment or brigade, the level of readiness or manning of a declared garrison, or the location of a declared unit).

If all errors, independent of type, are considered equally important, the number of inspections necessary to ensure that a prescribed level of data error, or greater, will be detected with a desired probability can be readily calculated.

Figure 4.4 gives as a function of the ratio of sites containing at least one exchange data error and the probability[6] P_i of discerning that error when on site, the number of OSI required for a detection probability of 90 percent of at least one site containing a data error.[7]

Relatively large numbers of OSI will be required to detect very small numbers of data exchange errors among the 1200 assumed declared Soviet sites. If every error is to be found, all sites would require inspection. If a specific type of exchange data error is difficult to detect, inspecting all sites will give increased, but not absolute, assurance of finding that type of error.

An answer to the question of how many OSI are needed to validate the data exchange requires finding the level of exchange data accuracy acceptable, the desired level of accuracy in estimating the TLE population, and the desirable level of confidence for detection of data errors. From Figure 4.2, to attain a 1 percent or less estimating error for the number of tanks, at a 95 percent confidence level, requires a stratified sample of 75 OSI selected from among the 375 declared tank sites. From Figure 4.3, a stratified sample of about 100 air

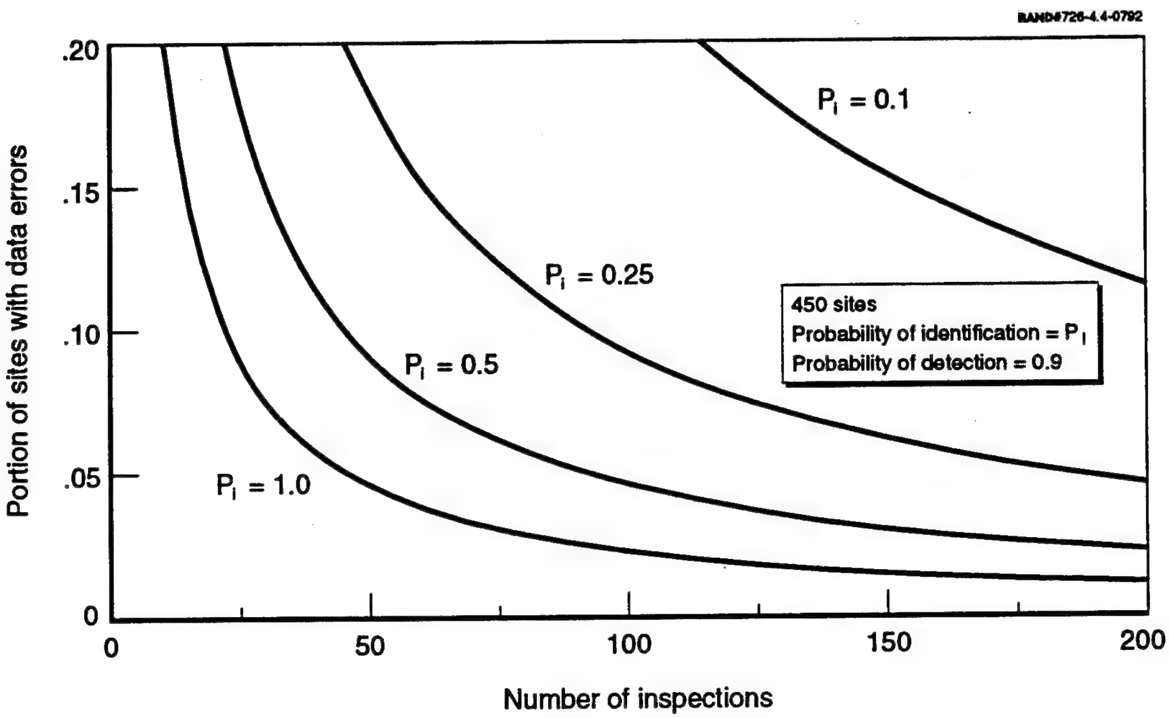

Figure 4.4—OSI Visits to Detect Declared Sites with Data Errors

[6]See Appendix A, part C.

[7]On average, two sites with data errors will be detected when the number of inspections is sufficient to yield a 90 percent probability to detect at least one such site.

bases for OSI would be required to achieve a 1 percent estimating accuracy of the declared Soviet aircraft population assumed to be deployed west of the Urals, with 95 percent confidence. An estimate more than 1 percent greater than the declared population number would indicate a true population size larger than what was declared.

Most sites containing tanks also are likely to contain other TLE, such as armored troop carriers (ATC), artillery, and attack helicopters. The bases with tanks and aircraft account for about 90 percent of all TLE sites and TLE in our illustrative example. The total number of OSI needed to estimate the declared number of TLE to within 1 percent of the actual TLE total, with 95 percent confidence, would be 175 divided by .9, or about 195 OSI. This assumes, as described above, that a high degree of TLE regularity exists at the declared sites. If, however, there is no basis for assuming such regularity during the validation period, then it might be prudent to visit all, or nearly all, sites containing TLE to ensure a sufficiently accurate counting of the TLE.

If the criterion for validating the data exchange is to ensure the detection of at least one site with an error with 90 percent probability, when 5 percent or more of the sites have errors, then about 40 OSI will be required, as shown in Figure 4.4, of the 1200 assumed declared Soviet sites. This assumes a perfect capability by the inspecting party to identify data errors. Given that 450 of the 1200 sites do not contain TLE, an additional 15 OSI of non-TLE sites will be required along with the 195 OSI of TLE sites described above, bringing the total number of OSI required to about 210.

If, however, there is difficulty in detecting data exchange errors at declared sites (that is, P_i is small), then, as shown in Figure 4.4, hundreds of sites may have to be visited. For the worst case scenario in which the TLE distribution at declared sites is uncertain, or highly variable, and data exchange errors are difficult to detect, nearly 1000 sites may have to be visited to achieve a desired level of data validation.

Some of the uncertainty may be moderated, if not eliminated, by agreement to ensure that the TLE at declared sites will not vary by more than some maximum amount during the four-month validation period, or by the inclusion of TLE serial or identification numbers in the data exchange. Inclusion of serial numbers could aid significantly in the TLE estimation process. If the TLE serial numbers were included, the validation process could be reduced to accepting the TLE numbers given in the data exchange and using OSI to find TLE without registered serial numbers. Identifying TLE by serial numbers could be cumbersome, but once done could make the task of monitoring the TLE population much easier.

If during the data exchange validation process, the number of data errors uncovered is greater than expected, it could lead to a call for the inspection of additional sites. Much will

depend on the nature of the data errors, their perceived impact on NATO security, and the causes and explanations for these reported data errors.

VALIDATION INSPECTION BY AERIAL SAMPLING

We have so far discussed the use of OSI to validate the data exchange that precedes the ratification of the CFE Treaty. An additional question is how to employ aerial inspections to aid in the validation process. The counting of TLE from aircraft may be difficult unless sensors with reasonably good resolution are employed and the inspected party cooperates by placing the TLE in locations readily visible from the air. Without such cooperation, validation through aerial inspection will be limited to detecting large or highly visible external site characteristics. Information gleaned from OSI or other sources could aid in calibrating the results of aerial inspections.

Aerial inspection during the validation period could locate, image, and identify all declared sites. All declared sites, and especially TLE sites, could thus be validated as to the number and types of units they contained. The imaging would serve as a data base for all NATO members and could be used to compare future aerial inspections after treaty ratification.

Figure 4.5 gives the number of Soviet sites viewed per aerial inspection sortie as a function of the sortie flight range and the average time spent over a given site to completely image it. The flight time allowed per aerial sortie is an issue for negotiation, as is the velocity of the inspection aircraft. Imaging dwell time will be strongly influenced by the type of on-board imaging sensor employed, which in turn will be influenced by the resolution required to distinguish between unit types.

Table 4.3 gives the sensor resolution requirements needed to detect and identify specific types of information.[8] Resolution of 3 to 5 ft would be required to distinguish between unit types and can be obtained by an assortment of imaging sensors at flight altitudes of 30,000 feet. For photographic imaging, clear weather and daylight are required. Underflying clouds at low altitudes could help, but may be unsafe. IR imaging could operate either day or night, but will require clear weather. An advantage to IR, which is sensitive to temperature variations, may be that it makes deception, like hiding TLE from aerial inspection, more difficult. Another possibility is the use of synthetic aperture radar (SAR)

[8]Amrom H. Katz, "Technical Collection in the 1980s," Chapter 5 in Roy Godson (ed.), *Intelligence Requirements for the 1980s: Clandestine Collection*, National Strategy Information Center, 1979.

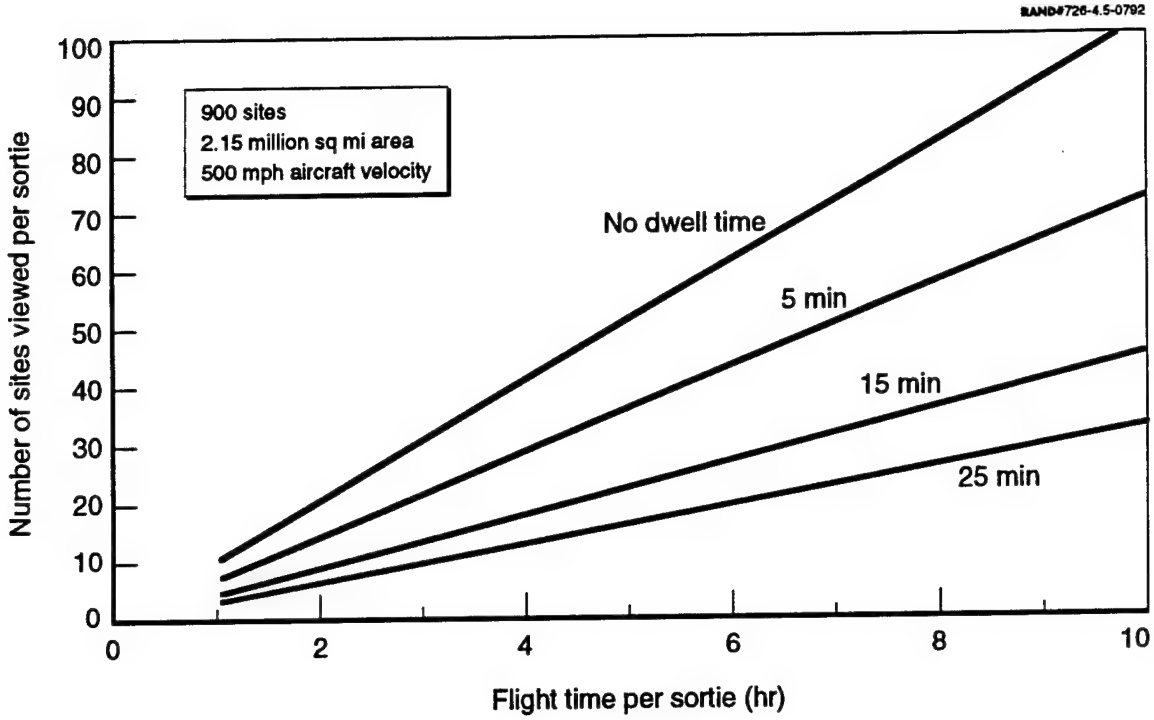

Figure 4.5—Aerial Inspection of Declared Sites

Table 4.3

CFE Aerial Inspection Resolution Requirements

Mission	Resolution
Locate military air and ground bases	10 ft
Assess type of military unit	3–5 ft
Counting TLE with cooperation (spaced TLE)	2 ft
Noncooperation counting TLE (known types)	1 ft
Noncooperation counting TLE (unknown types)	3–6 in.

that can operate day or night and in all-weather conditions. A problem, however, with employing SAR is that it may not yet be commercially available with the desired resolution. This leads to an interesting trade-off between efficient and timely imaging of the declared former Soviet sites versus the possible transfer of advanced SAR technology to potentially hostile countries earlier than they might otherwise acquire it.

For a 15-minute average imaging dwell time per site, about 40 sorties cover the entire 900 Soviet sites assumed, if the range of each sortie were 4000 miles and there were eight hours of flight at 500 mph. If the sortie time were reduced to three hours, about 105 sorties would be required. In essence, over 300 hours of flight may be required to overfly all former Soviet declared sites.

If imaging dwell time per site can be reduced to zero, aerial inspection flight time could be reduced to about 100 hours. With extended cloud cover over large parts of the USSR for extended periods, the use of SAR may be necessary to locate and classify declared sites within the 4-month validation period. A more detailed analysis that factors in operational flight times as a function of the on-board sensor and weather is beyond the scope of this effort. Optimally, multiple sensors for aerial inspection might be used to achieve adequate coverage and to make deception more difficult. Important in the ultimate choice of an on-board sensor will be the sensor's use in routine aerial inspections after the CFE Treaty has been ratified.

A question not expanded upon in this study is what finding a few data errors during the validation monitoring period means to the overall validation process. Much would depend on the nature of those errors and whether they were dealt with in negotiations between NATO and the WTO countries. On the basis of such findings, estimates can be made of how widespread such errors are likely to be.

5. RESIDUAL MONITORING AT DECLARED SITES

INTRODUCTION

After the CFE Treaty is ratified and over several years the WTO and NATO would reduce and destroy their excess treaty-limited equipment located in the ATTU region. After the TLE has been reduced by both sides to within treaty-prescribed limits, the era of residual treaty monitoring will begin. We next consider monitoring during this residual era.

The objective of the monitoring regime is to demonstrate to the inspecting party that the inspected party is complying with the terms of the treaty. Notionally, the way this may be achieved is for the inspecting party to organize his inspection regime to detect treaty violations or circumventions of some militarily significant quantity (MSQ) or magnitude, and not having found any treaty violations during the inspection, declare the inspected party to be in compliance with the treaty. At the same time, the inspecting party is assured that noncompliance may be no worse than a defined militarily significant quantity.

Militarily or politically significant treaty violations must be defined, as must how rapidly they should be detected by the monitoring regime. Military significance can be expressed in terms of increased numbers of tank or motorized rifle (MR) units, or in numbers of TLE, such as number of tanks, ATC, artillery, attack helicopters, etc. Table 5.1 gives Soviet unit types and their TLE profiles. Militarily significant infractions or circumventions could include reported increases in force readiness, force exercises, or changes in the command and control structure of Soviet ground or air forces.

An important characteristic of a monitoring regime is timeliness in detecting treaty circumventions or violations. A monitoring objective is the early detection of militarily significant force changes and mobilization to allow the inspecting party to react politically and militarily to defend against an impending attack. Large numbers of former Soviet weapons and forces continue to be deployed east of the Ural Mountains, and the large-scale mobilization and rapid movement of those forces westward should be readily observed by NTM. It was appropriate, therefore, to emphasize in a CFE Treaty monitoring regime the detection of a slower but inexorable buildup of TLE at declared Soviet sites west of the Urals. A military buildup west of the Urals could occur almost anywhere, but would be least costly to the USSR to have that occur at declared sites.

Table 5.1

Approximate TLE Unit Profile of Soviet Forces

Unit	Tanks	ATC	Artillery
MR regiment	40	115	18
MR division	220	350	160
Tank regiment	97	51	18
Tank division	328	260	184

where 1000 tanks = 5 MR divisions or
3 tank divisions
or
2 MR divisions plus
2 tank divisions

It was assumed that the inspection teams will have access to most, if not all, on-site facilities, and that notification of a site inspection will be made six hours before the inspection team arrives at the inspected site. We further assume that a site visit will allow for all garrisons at that site to be inspected as well as all nongarrison areas within the site area. Ostensibly, the OSI regime will sample declared sites for timely estimates of the TLE population and assurance that other aspects of the CFE Treaty are being complied with.

An important issue is how aerial inspections can be effectively used as part of a residual monitoring system. Depending on the amount of flight time allowed for an aerial inspection, varying numbers of declared sites could be overflown per sortie. The scope and utility of aerial inspections can be affected by several important factors—treaty limitations of sensor resolution, deception by the inspected party, poor weather conditions, and time of flight limitations.

Aerial inspections are expected to be conducted at altitudes of about 30,000 feet with limited resolution sensors. In the residual era, aerial inspections would be useful in detecting changes at declared sites—new or enlarged garrisons, new or extended runways or aircraft hangers, or new or improved protective revetments at military air bases. Aerial inspections might monitor large-scale exercises or movements of TLE. Sighting by aerial inspection of a change at a suspect site could trigger an on-site inspection. Table 3.1 lists some of the categories of change at declared sites that would be desirable to detect by OSI and aerial inspection.

An important notion in the development of an inspection regime is whether that regime will be required to detect circumventions that are transient, such as too many TLE, perhaps 100 or 200 more in a zone than are permitted by the treaty but that remain for only

a day or two, perhaps as new equipment replaces old. Alternatively, the regime could look at changes that are substantive and of longer duration, such as the permanent deployment of increased numbers of TLE at declared sites, new military units at new undeclared sites, or new and improved types of armament and equipment.

In developing an inspection regime for the residual period, we consider how cooperation, or lack of cooperation, by the inspected party affects the ability of the inspecting party to achieve its monitoring objectives. Other issues include the potential utility of tagging or identifying TLE as a monitoring aid.

THE MODEL

In the residual monitoring era, after reductions to treaty TLE limits are reached, former Soviet forces in Central Europe are expected to return to the former USSR. The number of declared sites in the former USSR, and those containing TLE, could increase or decrease. Returning forces could be garrisoned at new declared locations or at existing declared locations. The former Soviets could keep bases open and reduce the number of forces and TLE per site, maintaining units at partial strength. They may elect to reduce the number of sites, maintaining units at current strength. They may locate large quantities of TLE at designated storage sites.

Table 3.2 in Section 3 gives the assumed breakdown of Soviet declared sites within the former USSR during the residual monitoring period. To illustrate the use of statistical sampling methods in estimating total numbers of TLE at declared Soviet sites, we have assumed a distribution of tank units for the residual period; see Table 5.2. This distribution assumes that the Soviets reduce the total number of sites with TLE, keeping force levels at the remaining sites at about current levels. As with the data exchange validation described in the previous section, we initially assume that there will be a high degree of regularity in the number of TLE at units of the same type.

In validating the data exchange, the inspection regime was designed to estimate on a one-time basis the total TLE population to within some specified accuracy. In the residual monitoring era, the objective is to achieve a desired level of accuracy in estimating TLE on a continuing basis and to detect military or political violations or changes in a timely manner.

We have assumed for purposes of analysis that violations or changes will be uniformly distributed either among the TLE sites or the 900 declared Soviet sites. As before, sites chosen for aerial inspection are assumed to be selected at random and sites may be overflown on subsequent sorties. For flight times of about six hours or more, or for flight ranges that exceed about 3000 miles, this assumption may be reasonable. At these flight ranges it is

Table 5.2

Post-Ratification Illustrative TLE Tank Distribution (USSR: ATTU Only)

Unit type	No. of Sites	No. of Tanks	μ_i	σ_i
Battalion	25	875	35.0	3.50
Light regiment	40	3200	80.0	5.29
Heavy regiment	10	1200	120.0	6.48
Light division	20	3600	180.0	7.94
Division	10	3000	300.0	10.25
Other	20	125	6.25	1.48
Total	125	12000	$\mu_p = 96$	$\sigma_p = 81.4$

possible on any sortie, irrespective of where the flight originated in the European portion of the USSR, to reach any other site in the European Soviet Union during that sortie. Thus, in principle every declared site in the treaty-monitored region of the USSR can be inspected along with any other declared site in that region on any given sortie of about 3000 miles or more range.

Practically, however, a totally random selection of sites for either aerial or on-site inspection may not be realistic operationally nor is likely to be the most cost-effective way to proceed. There may be instances in which an OSI and an aerial inspection should overlap, or nearly so. Indeed, the synchronization of aerial and OSI may be a deterrent to the inspected party attempting to move TLE off site before an OSI begins or use other deceptive means.

COUNTING THE TLE

To monitor the treaty TLE limits, statistical methods are used to test the hypothesis that the average number of TLE observed in a sample of randomly selected sites comes, with high confidence, from a population equal to or less than that allowed by the treaty, and with equal confidence does not come from a TLE population that exceeds the treaty limit by more than some significant and predetermined amount.

The greater the confidence desired in accepting or rejecting the hypothesis, i.e., the more likely the sample will represent the actual population, the larger the sample size required. The rate at which inspections are performed will depend on how rapidly detection of militarily significant violations or changes is required. Nominally, halving the time to detect violations or changes doubles the rate of inspection.

The statistical approach will depend on how much information is available on the characteristics and statistical parameters of the TLE population. If the number of TLE among like units is highly regular, then stratified sampling methods are appropriate to

estimate TLE population size. If there are few data on how TLE are distributed, or there is great irregularity in numbers of TLE at like units, a less efficient estimation method based upon random sampling will be used.

For the distribution of tanks and sites listed in Table 5.2, calculations based on a simple stratified sampling technique[1] were used to determine the number of OSI required to find a desired level of confidence that the total population of tanks does not exceed a militarily significant quantity. Figure 5.1 gives the number of OSI required, based on random sampling, to detect, with 95 percent confidence (P_c), critical increases in tank numbers beyond the treaty limits of 12,000 as a function of the tank population standard deviation. As in the previous section, large uncertainties in a priori knowledge of tank locations or distributions among the sites generate a need for greater sample sizes.

If there were little or no a priori data on the distribution of tanks among the 125 declared tank sites, or there were continual movement of tanks between sites, with the doubling or tripling of the number of tanks at some sites and with none at others, then with the standard deviation of tanks for our assumed tank population of 80, it would require about 32 OSI among those 125 sites to detect an increase of 4000 tanks with 95 percent confidence.

Figure 5.2 shows the number of OSI needed to ensure, at given levels of confidence, the detection of different numbers of additional tanks introduced into the 125 assumed Soviet tanks sites when there is regularity of TLE numbers between like units, as described in Table 5.2, and where, therefore, tank population estimates can be more efficiently obtained by stratified sampling methods. Figure 5.2 indicates about a 35 percent reduction in OSI required to detect the 1000 additional tanks, if the statistical level of confidence is dropped to .90 from .95.

The selection of a confidence level will be influenced by political and economic considerations. The total number of OSI allowed by treaty to each side is a bound in selecting a confidence level; the desire to use OSI for non-TLE sites will be another limiting factor.

Figure 5.3 gives the number of OSI required to detect a militarily significant increase in tank numbers when the 12,000 Soviet tanks are distributed over 250 declared Soviet sites. Table 5.3 gives the assumed distribution of tanks among the 250 sites. This distribution would have reflected a Soviet decision to keep most existing sites in the ATTU region and to reduce the numbers of TLE per site. Even though the average number and standard

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[1]Simple stratified sampling assumes that sites are selected randomly across the spectrum of strata. No stratum is more capable of avoiding inspections, and thus no stratum yields an advantage in hiding new TLE deployment. See Appendix B, part B.

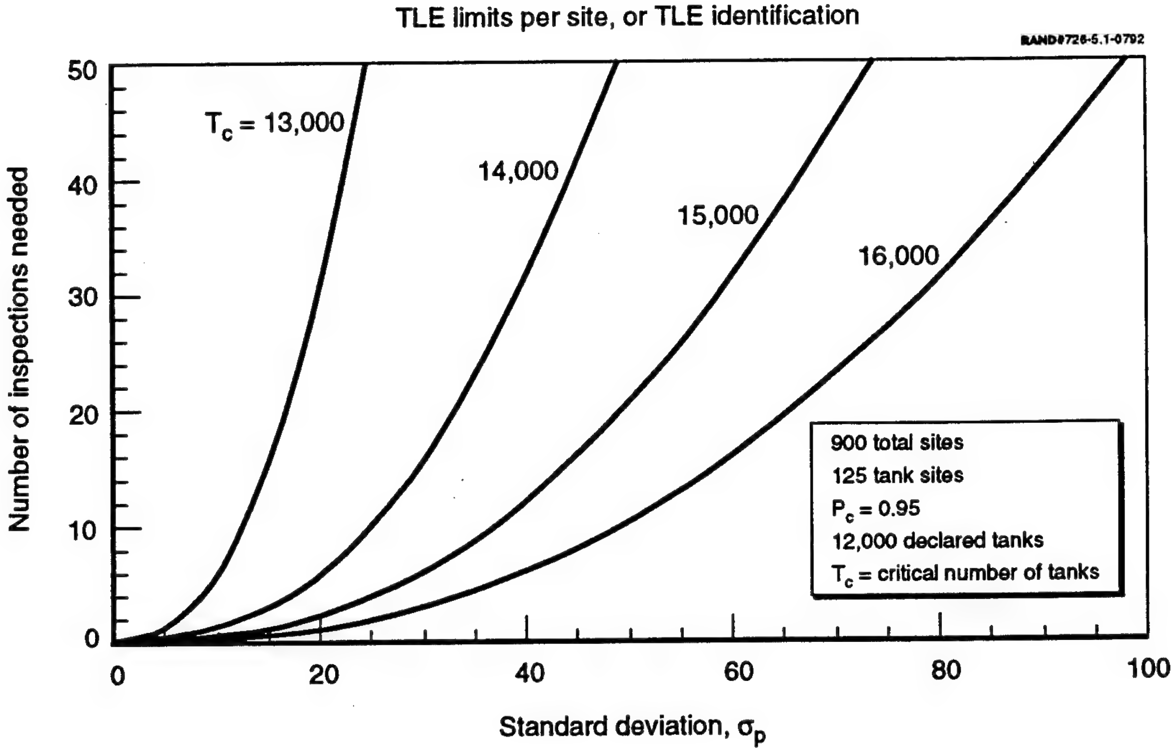

Figure 5.1—OSI Required to Detect TLE Increases

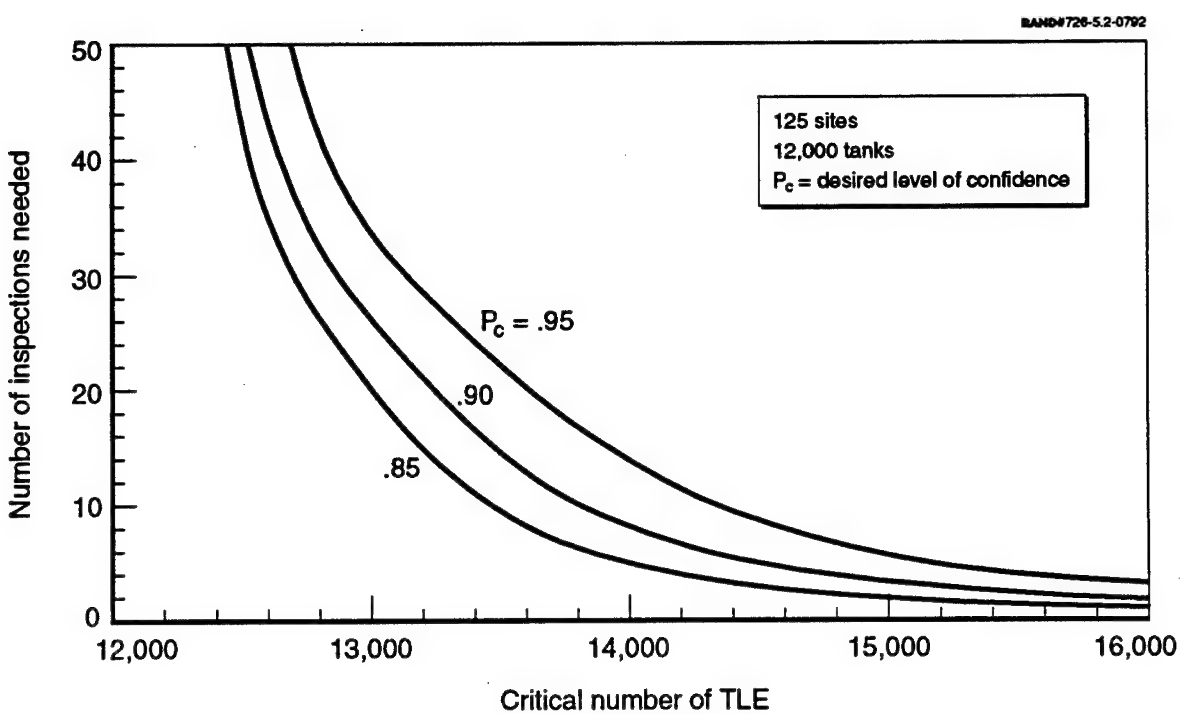

Figure 5.2—OSI of TLE Numbers at Declared Sites, Post-Ratification with Stratified Search

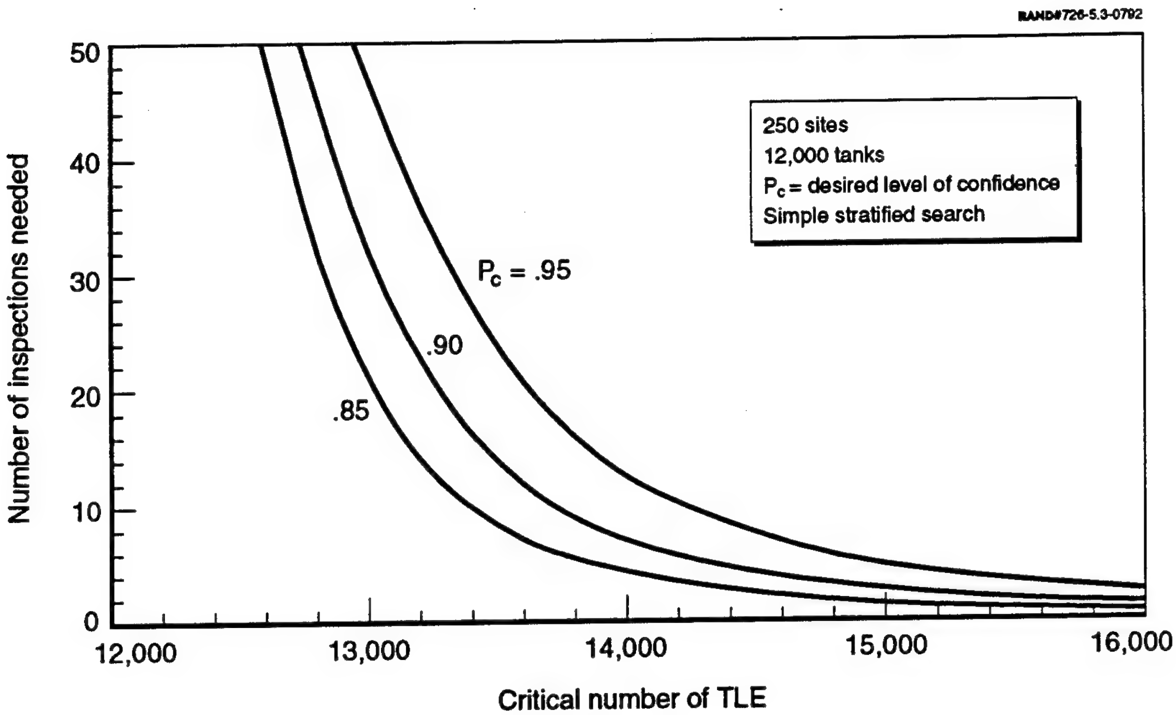

Figure 5.3—Post-Ratification: Illustrative TLE Tank Distribution (USSR: ATTU Only)

Table 5.3

Post-Ratification Illustrative TLE Tank Distribution (USSR: ATTU Only)

Unit type	No. of Sites	No. of Tanks	μ_i	σ_i
Battalion	50	875	17.5	1.75
Light regiment	80	3200	40.0	65
Heavy regiment	20	1200	60.0	24
Light division	40	3600	90.0	97
Division	20	3000	150.0	12
Other	40	125	3.125	0.74
Total	250	12000	$\mu = 48$	$\sigma_p = 42.6$

deviation for tanks at these declared sites were cut in half, a comparison of Figures 5.2 and 5.3 shows a 20 to 25 percent increase in OSI needed to detect increases of 1000 to 2000 tanks when the number of tank sites is increased from 125 to 250.

The calculations given in Figure 5.3 assume a high degree of regularity in the number of TLE at the Soviet sites, as depicted in Table 5.3. Figure 5.4 gives the number of OSI

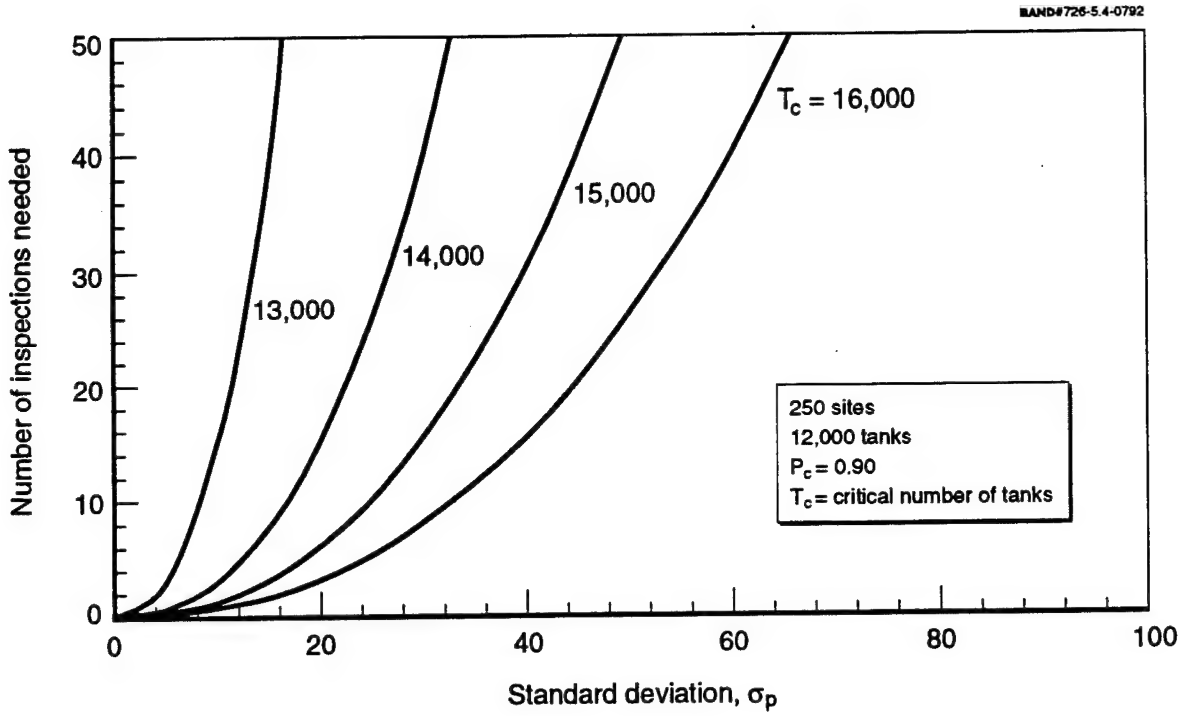

Figure 5.4—OSI of TLE at Declared Sites, Post-Ratification with Random Search

required when a priori data on TLE locations is limited or nonexistent and the population standard deviation is used to estimate tank population size, as a function of the population standard deviation and the incremental number of tanks to be detected.

Whatever is agreed to by treaty regarding the frequency and limitations of OSI may not be fully understood until actual site monitoring gets under way. Thus, if numbers of OSI are negotiated to ensure accurate TLE estimates or timely detections of violations, or both, assuming there will be a lack of cooperation, those numbers of OSI may be excessive if the inspected country is reasonably cooperative. Assuming reasonable cooperation by an inspected country or a high degree of regularity in the distribution of their TLE as the basis for negotiating the number of OSI could lead to less accurate TLE estimates and less opportunity to detect significant changes in TLE numbers if there is a total lack of cooperation by the inspected party. Distributing TLE over larger numbers of sites could also influence the number of OSI required.

COUNTING TLE WITH SUPPORTIVE TREATY MEASURES

Approach

The object for having treaty supporting measures would be to limit the need to sample declared sites to estimate the TLE population. To monitor compliance with supporting measures, inspections would have to locate the TLE at inspected sites and determine whether they were legitimate, accounted-for TLE. For large-area sites, there may be some difficulty in using OSI alone to determine that TLE are not being stored at remote locations on that site.

Three approaches were considered to support TLE monitoring. The first was tagging of each TLE with a unique marker that could not be readily removed or changed. A second possibility was to identify all TLE by their serial numbers. Either way, OSI would be seeking TLE without proper tags or without proper serial numbers.

A third approach was for both sides to agree to limits on the maximum numbers of TLE allowed to be located at each declared site. This would allow OSI to determine whether the number of TLE at a site exceeds the maximum for that site. In all instances, a party would be presumed to be in treaty compliance if no illicit TLE were found or TLE limits were not violated at an inspected site.

There are important questions of cost and technical and operational feasibility associated with the use of tagging, serial numbers, or treaty constraints on numbers of TLE allowed at sites. These cost and feasibility issues will not be addressed here.

With these support mechanisms, the process of monitoring declared sites to detect TLE treaty violation reduces statistically to randomly sampling the declared sites. In theory, this implies that any declared site could be chosen for OSI at any time and repeatedly. The criteria for determining compliance to TLE limits at declared sites would be the absence of illegal TLE or an excessive number of TLE.

If frequent infractions, such as a few extra or untagged TLE, are found at sites or extensive treaty circumventions are found at a few sites, the significance of these events could be calculated by the statistical methods discussed in the previous section.

An objective for OSI is timely detection of infractions when relatively widespread, that is, when small numbers of excess or illegal TLE are distributed at numerous declared sites. Figure 5.5 gives the number of OSI necessary to attain a probability of detecting at least one TLE infraction or circumvention as a function of the percentage of the declared sites that have such infractions or circumventions and the conditional probability P_i that an infraction is uncovered at an inspected site. The smaller the percentage of sites with violations that

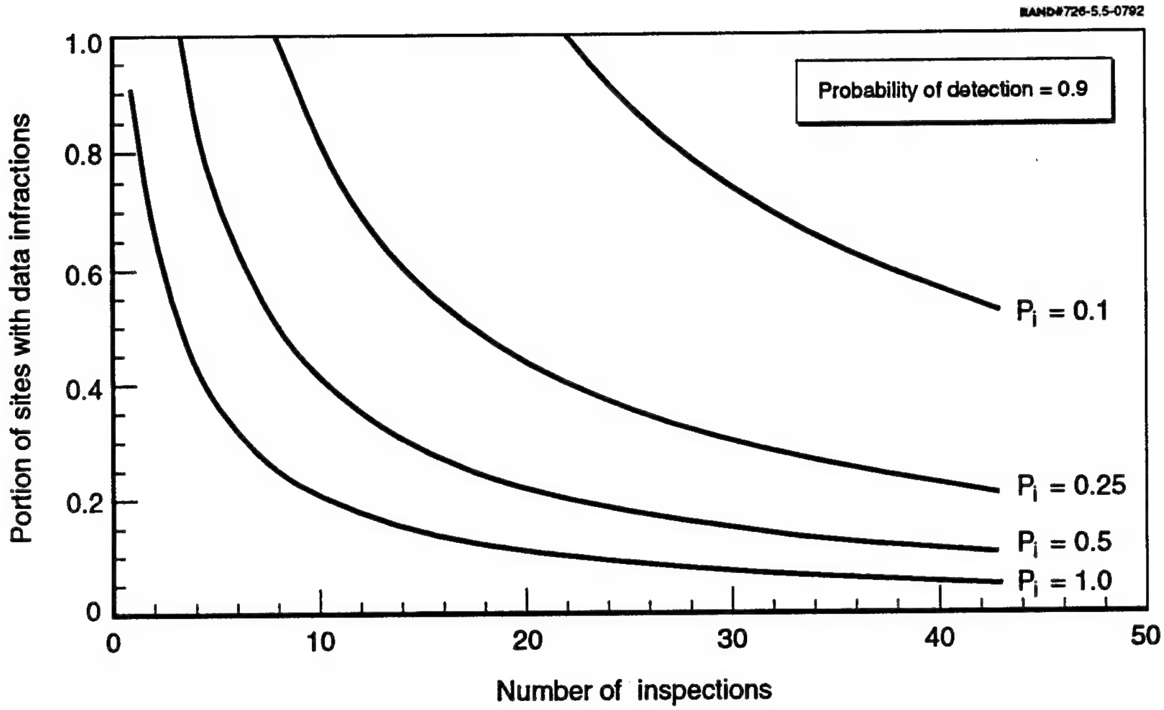

Figure 5.5—OSI Search for Declared Sites with Data Infractions

OSI must detect, the larger the number of OSI required. Compliance would be established at declared sites if no violations are found.

Figure 5.6 gives the probability of detecting a violation as a function of the percentage of declared sites, P_v, that are in violation and number of OSI. The decision on how rapidly OSI should uncover infractions or circumventions of a particular magnitude will be based on a variety of factors, including the nature of the political/military environment in Europe. As will be noted from Figures 5.5 and 5.6, OSI can in principle do better detecting many violations spread across the declared sites than detecting violations spread over a smaller number of sites even if the violations are large.

We have assumed that deceptive methods or OSI team limitations in detecting infractions can be characterized by a variable parameter P_i, with value between zero and one. There is no obvious way, however, to establish a priori what appropriate value of P_i to use, whether caused by OSI team limitation or by deception.

With one or another of the supportive measures in effect, the movement of TLE to and from declared sites ceases to be as important. Perhaps some combination of identification of TLE by serial number and a limit on the number of "extra" TLE at a declared site would be

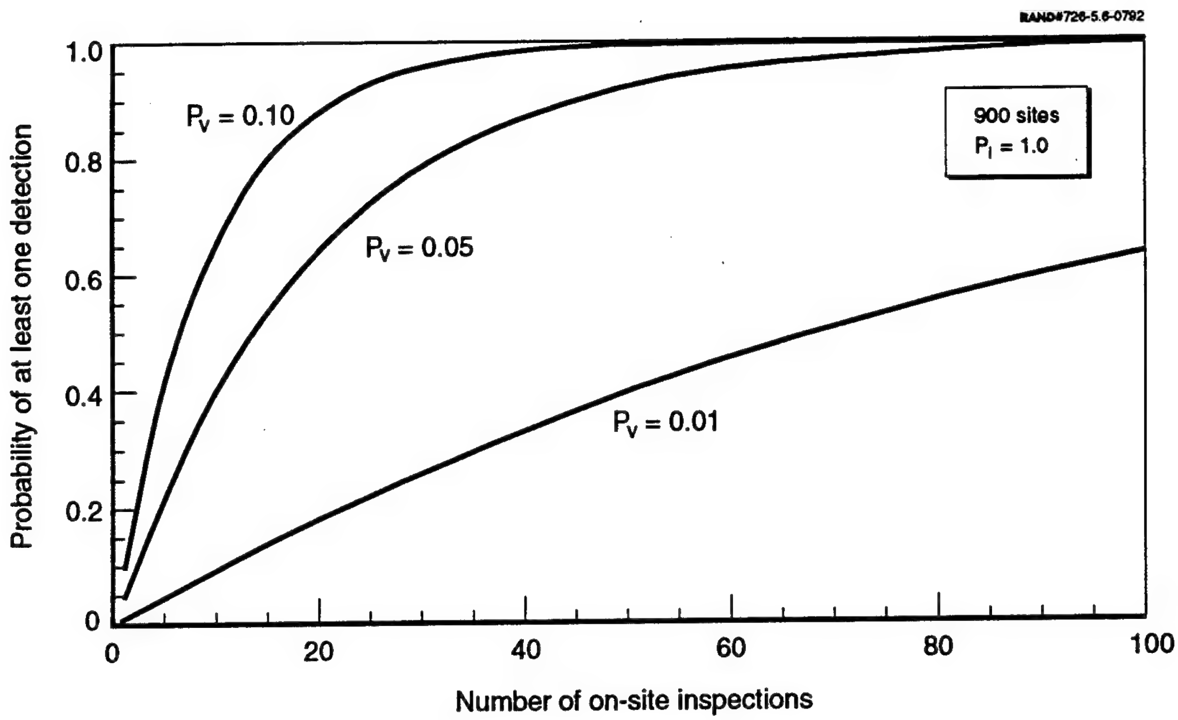

Figure 5.6—OSI Search for Violations at Declared Sites

most effective in aiding TLE monitoring. Aside from the important question of hiding TLE, treaty compliance would be established more readily in real time if support measures were in place and statistical estimates of TLE population sizes were not required. It is uncertain whether statistical estimates of TLE population size would be accepted by the inspected party as a basis for determining noncompliance.

Detection of Other Violations, Changes, Etc.

In addition to estimating or counting TLE, there are other treaty limits and requirements to consider. There is likely to be an annual update and data exchange negotiated for each side's force changes and TLE deployments. Confirmation of these changes might be an objective for OSI. Notification of certain actions may also be required, inter alia, of major movements of TLE, in and out of storage sites, and may be among declared sites as well, or major military exercises, the construction of new declared sites and facilities, and changes in military command and control organization.

There are confidence-building measures that can be achieved through treaty monitoring that are not related to specific treaty limitations or requirements. The upgrading of TLE equipment will not be limited by treaty. Force reductions, however, can be offset by

improvements to TLE as well as other qualitative force changes. The ability of each side to be aware of the other side's deployment of improved TLE or other force-enhancing activities can become an important CBM.

Figure 5.7 gives the detection probability (P_D) for violations and changes at declared sites as a function of the number of OSI and the probability, P_i, of detecting a violation or change at an inspected site. Figure 5.8 gives the number of OSI required to detect, with 90 percent probability, at least one violation or change when different percentages of the declared sites have violations or changes.

The detection of some types of violations and changes at declared sites can be accomplished by aerial inspection, particularly the introduction of new military units or facilities. As discussed above, the utility and capability of aerial inspection to monitor declared sites will depend on a variety of technical and operational factors and on what the CFE Treaty inspection protocols allow.

Figures 5.9, 5.10, and 5.11 give for different sortie flight times the probability of at least one detection by aerial inspection of a violation or change at a declared site, when five sites are in violation, as a function of the number of aerial sorties flown and the conditional

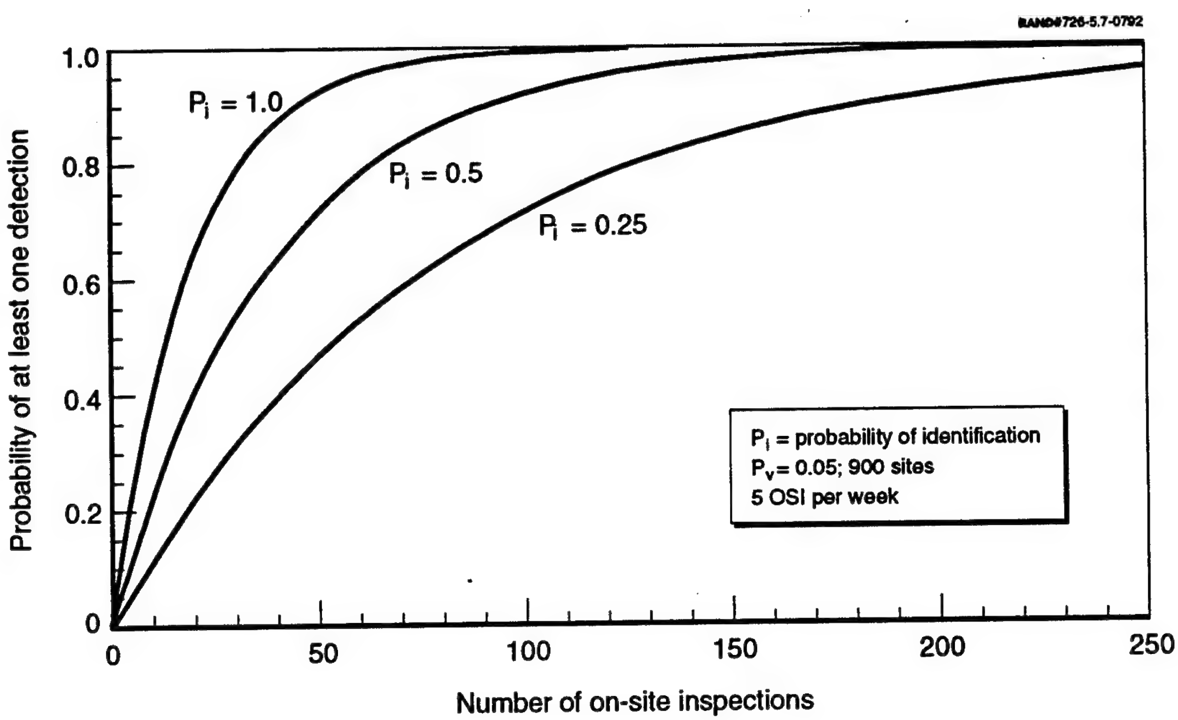

Figure 5.7—Inspections Needed to Detect Wide-Scale Infractions, Violations, or Changes

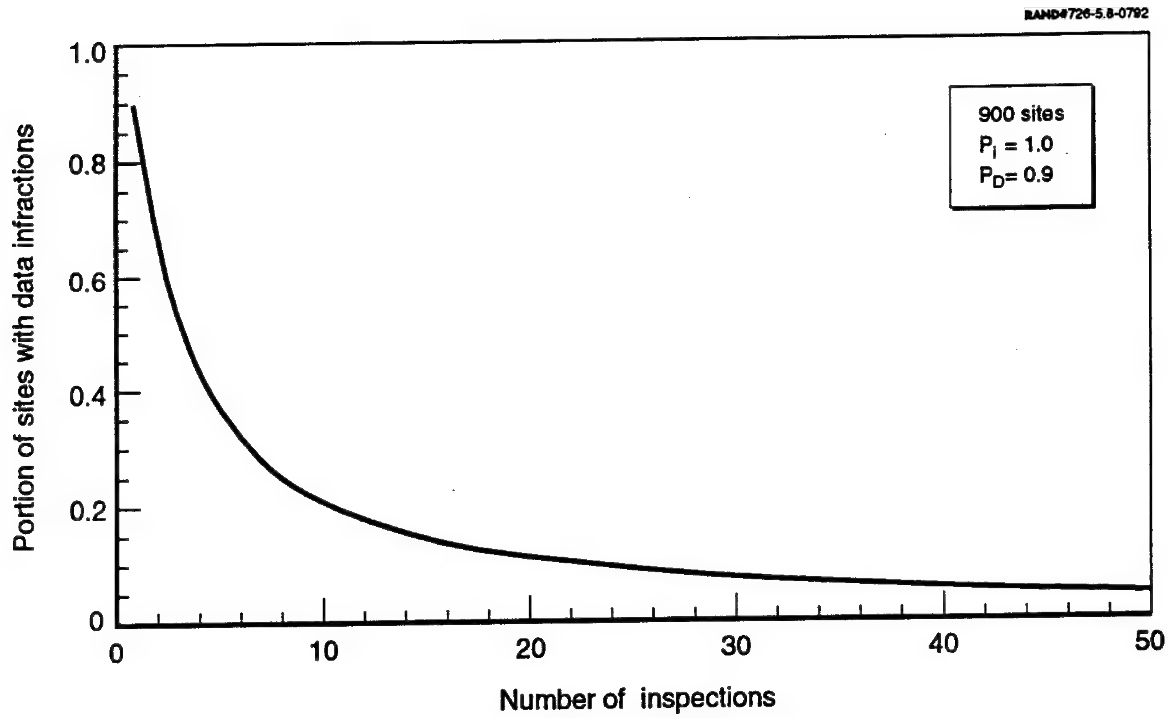

Figure 5.8—OSI Search for Declared Sites with Data Infractions

probability that a violation or change was detected when the site with that violation or change was imaged by the inspecting aircraft. These results assumed either a 5 or 15 minute average imaging dwell time per site inspected, and that 0.55 percent of the sites have violations or changes.

The results in Figures 5.9, 5.10, and 5.11 also demonstrate what reductions in imaging dwell time per site can have on increasing the effectiveness of aerial inspections, especially if sortie flight times are to be limited.

We have assumed that significant site changes, such as the introduction of new units, could be detected with imaging resolutions of about 3 to 5 ft, and that resolution could be obtained by IR, photographic, or radar sensors. An issue is whether the aerial inspection system should have the widest opportunity to inspect, day or night, and in all weather, as with a SAR sensor, or whether the use of an IR sensor with its operational limitations but with its potential to uncover attempts to hide equipment would be a better choice, or whether photographic imaging with its large field of view but operational constraints would be most effective. To uncover large and significant activities, violations, or site changes at declared sites may not require the higher resolution of IR or photography. It remains a question of

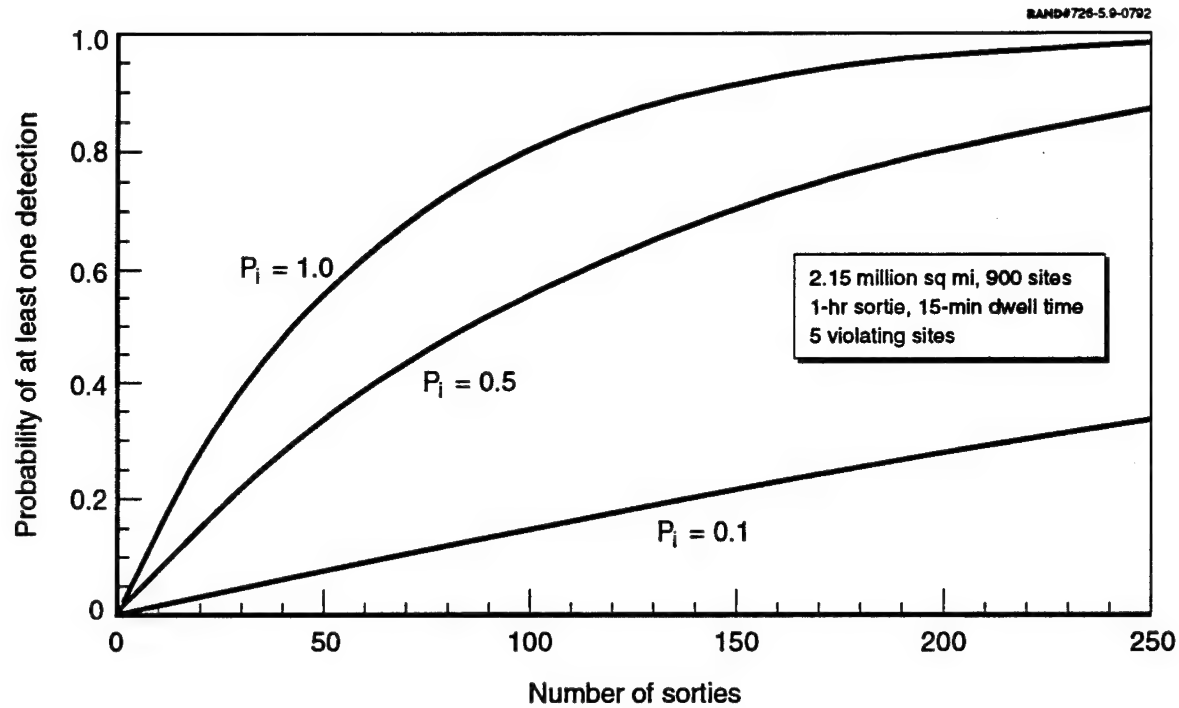

Figure 5.9—Aerial Inspection of Declared Sites
(1-hr Sortie)

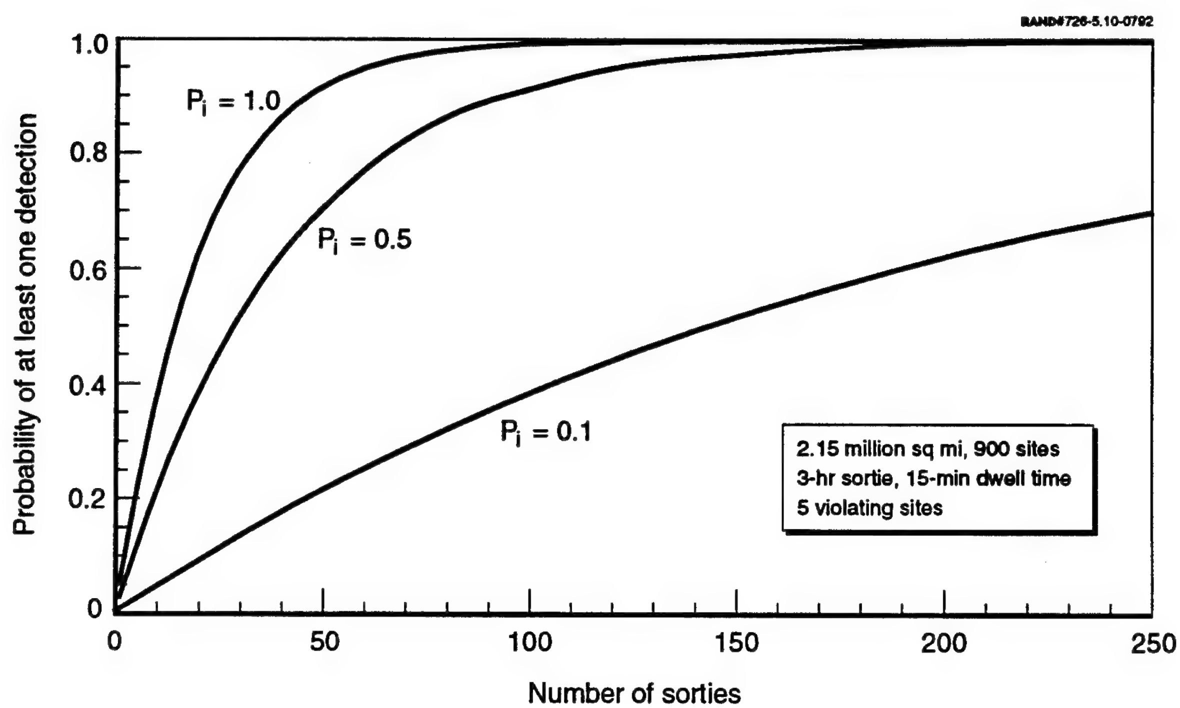

Figure 5.10—Aerial Inspection of Declared Sites
(3-hr Sortie)

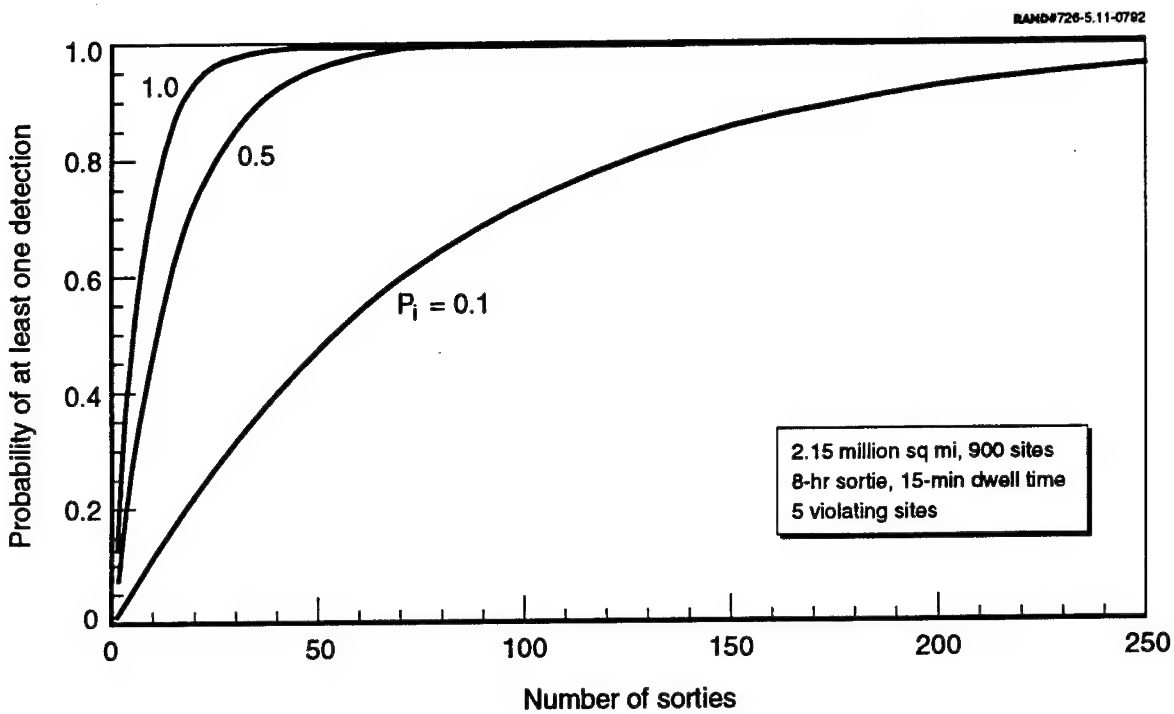

Figure 5.11—Aerial Inspection of Declared Sites (8-hr Sortie)

whether significant changes or violations, such as introducing new battalions or regiments to declared sites, could easily be camouflaged or hidden from one or all of the imaging sensors.

To illustrate the potential role of aerial inspection to monitor important aspects of a CFE treaty, Table 5.4 shows the number of aerial inspections needed to detect increasingly larger and more widespread violations among the declared sites. It was assumed that military tank units, from company to division size, were deployed over different numbers of the declared sites, where P_i, the probability of detecting each size unit when imaged by aerial inspection, was assumed to increase with the size of the unit, but for purposes of illustration the specific P_i values were assumed.

If 1000 additional tanks deployed at declared sites in the ATTU region of the former USSR were judged to be militarily significant, then, based on results shown in Table 5.4, it would presumably take 21 or fewer sorties to detect at least one of those violating sites. The results in Table 5.4 are sensitive to the P_i values assumed and the sortie range and average site imaging time. Table 5.5 gives comparable results to those in Table 5.4, where the imaging dwell time over a site is assumed to be five minutes and the sortie range is only 1500 miles. Although the parameters used were somewhat arbitrarily selected, the results in

Table 5.4

Illustrative Potential of Aerial Inspection of Declared Sites (4000-mi sortie range)

How many sorties does it take to detect at least one violation with 90% confidence?									
Violation Type			If the number of violating sites (units) is						
New Unit	No. of tanks	P_i	1	2	5	10	25	50	100
Company	10	0.1	903	453	183	93	36	18	9
Battalion	30	0.25	363	183	75	36	15	9	6
Regiment	100	0.75	123	63	24	12	6	3	3
Division	300	0.90	102	51	21	12	6	3	3

NOTES: 900 sites
15-minute dwell time
4000-mile sortie range
2.15×10^6 mi^2 area

Table 5.5

Illustrative Potential of Aerial Inspection of Declared Sites (1500-mi sortie range)

How many sorties does it take to detect at least one violation with 90% confidence?									
Violation Type			If the number of violating sites (units) is						
New Unit	No. of tanks	P_i	1	2	5	10	25	50	100
Company	10	0.1	1251	627	252	126	51	27	15
Battalion	30	0.25	501	252	102	51	21	12	6
Regiment	100	0.75	168	84	36	18	9	6	3
Division	300	0.90	141	72	30	15	6	3	3

NOTES: 900 sites
5-minute dwell time
1500-mile sortie range
2.15×10^6 mi^2 area

Table 5.5 indicate that with reduced sortie range aerial inspections may be effective in detecting an infiltration of 2000 tanks among declared sites in the USSR employing about 15 aerial inspection sorties.

A reduction to a 500-mile, or one-hour, sortie range further increases the number of aerial inspection sorties required of declared Soviet sites. Table 5.6 shows the results in number of aerial inspections required to detect at least one of the violating sites when the sortie range is reduced to 500 miles and the average dwell time for imaging a site is five minutes. Shorter range aerial inspections could, as suggested by this illustrative example, detect the deployment of 4000 or more tanks with about 12 to 15 sorties.

Table 5.6

Illustrative Potential of Aerial Inspection of Declared Sites (500-mi sortie range)

How many sorties does it take to detect at least one violation with 90% confidence?									
Violation Type			If the number of violating sites (units) is						
New Unit	No. of tanks	P_i	1	2	5	10	25	50	100
Company	10	0.1	3753	1878	753	378	150	75	39
Battalion	30	0.25	1503	753	303	150	60	30	15
Regiment	100	0.75	501	252	102	51	21	12	6
Division	300	0.90	417	210	84	42	18	9	6

NOTES: 900 sites
5-minute dwell time
500-mile sortie range
2.15×10^6 mi^2 area

It would appear, then, that a reasonable role for aerial inspection might be to monitor the declared Soviet sites for significant changes—the introduction of new units and facilities. Aerial inspections should be able to overfly multiple sites per sortie and thus allow for a relatively rapid and high rate of inspection for declared sites. Moreover, the coordination of OSI and aerial inspection in time and location could offer mutual benefits in deterring aberrant behavior by the inspected party. The arrival of an aerial inspection at a site just before or after an OSI could inhibit the use of deceptive measures by the inspected party.

6. AERIAL INSPECTION FOR SUSPECT SITES

There are alternative approaches to using aerial inspection to find new suspect sites located in the ATTU region of the USSR. One approach would be to search for new suspect sites by aerial inspection over wide areas. Declared sites would be imaged as they were overflown; all locations in the ATTU region of the USSR would be equally likely to be overflown and imaged. A second approach would be to search for new suspect sites when flying between aerial inspections at declared sites. Each of these approaches is discussed below.

The utility of aerial inspection in finding new suspect sites will be affected by a number of variables. Table 6.1 gives an estimated imaging swath width and resolution attainable from a 2-ft focal length camera or from a synthetic aperture radar (SAR) aboard an aircraft flying at 30,000 ft altitude. The SAR performance assumed and given in Table 6.1 can in principle be obtained in a variety of ways.[1] The hypothetical SAR used in these calculations reflects what is believed to be 10 to 20 year old U.S. technology using about 100 watt average power, less than 30×10^6 processor operations throughput capacity, and limited bandwidth. We do not know how this compares to Soviet SAR capabilities or what may be available in other nations.

Figure 6.1 gives the number of aerial sorties required to image the 2.15 million square miles of the European portion of the former USSR by each of these systems, assuming 4000 miles of sortie range, as a function of sensor resolution. For the photo system, the estimated resolution at its nadir is less than one foot when at 30,000 ft flight altitude. The photo resolution defined in Figure 6.1 is at its maximum range. For any specific resolution selected in Figure 6.1, the average resolution of the photo system will always be better than that of the SAR; that is, the SAR has a constant resolution over its imaged area.

Irrespective of which sensor is employed for wide-area search, a basic question is the rapidity with which the imaging can be reviewed. Thousands of images per hour of flight are expected to be recorded. It is assumed that some combination of automated comparison with past imaging to isolate new facilities and photo interpreters will be used to identify new suspect sites. The effect of delayed photo interpretation will be discussed in the next section.

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[1]See S. A. Hovanessian, *Introduction to Synthetic Array and Imaging Radars*, Artech House, Dedham, MA, 1980.

Table 6.1

Assumptions for Aerial Inspection

SAR (all-weather)	4000 n mi per hr, 10-ft resolution, 10-mile swath
	270 n mi per hr, 3-ft resolution, 0.54-mile swath
Optical (2-ft focal length)	2.46-ft resolution, 15.5-mi ground range, 30,000-ft altitude
	6.07-ft resolution, 31-mi ground range, 30,000-ft altitude
	11.15-ft resolution, 46.6-mi ground range, 30,000-ft altitude

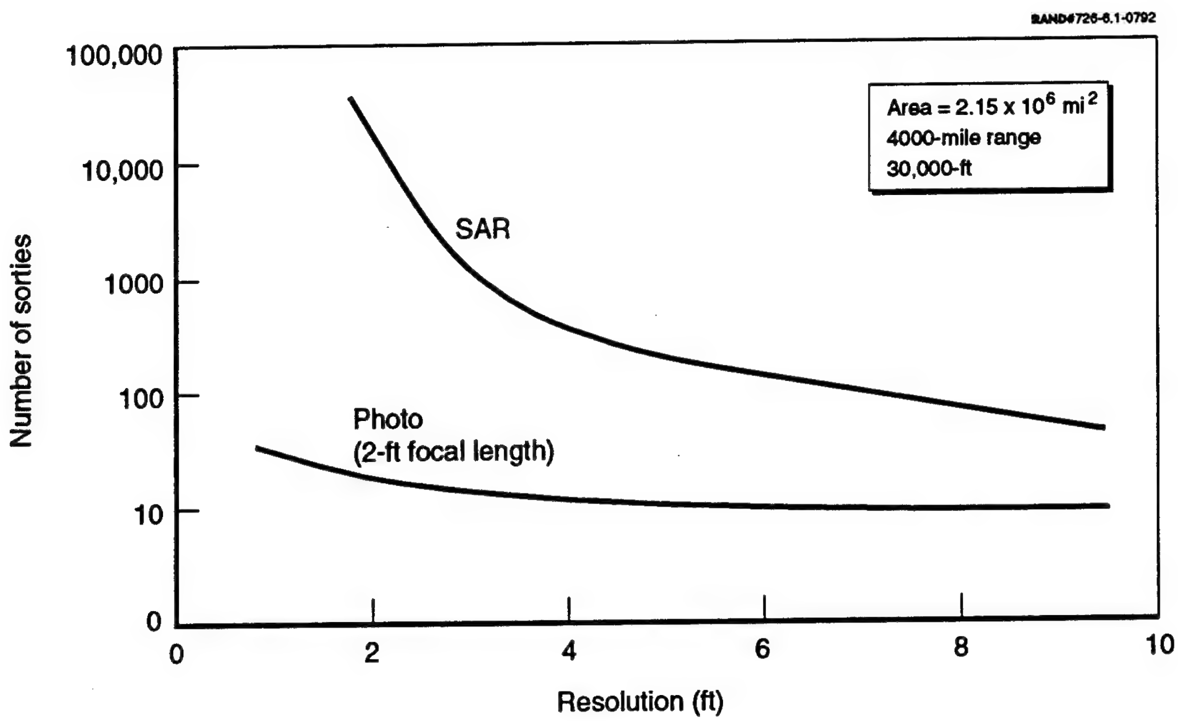

Figure 6.1—Sorties Required to Fully Cover USSR West of Urals

The selection of a 2-ft camera focal length was based on having adequate resolution to detect suspect sites but a resolution sufficient to constitute a serious intelligence threat from aerial inspections. Table 4.3 in Section 4 indicates that newly deployed suspect military sites could be detected by 10-ft resolution photography. (It is assumed that 10-ft SAR resolution will yield equivalent detection.)

The probability of finding a new suspect site on a single aerial inspection was assumed to be equal to the ratio of total area imaged during a sortie divided by the area of the USSR west of the Ural Mountains multiplied by the conditional probability P_i that the site will be

detected if it has been imaged. Thus, the longer the sortie range and the wider the imaging swath width, the greater the probability of imaging a suspect site during a given sortie.

It was also assumed that every point in the former USSR west of the Urals was equally likely to be overflown on any given sortie, irrespective of the sortie launch point in the USSR. The area covered by one aerial sortie flight in the USSR was independent of the area overflown on the next sortie, and sites could be overflown on consecutive sorties.

Figure 6.2 gives the probability[2] of a single sortie detecting five new suspect sites located in European Russia, for varying sortie ranges and as a function of imaging sensor swath width. Figures 6.3 and 6.4 give the detection probability of five randomly located suspect sites by a single 4000-mile sortie as a function of sensor swath width and the maximum area in which suspect sites are located.

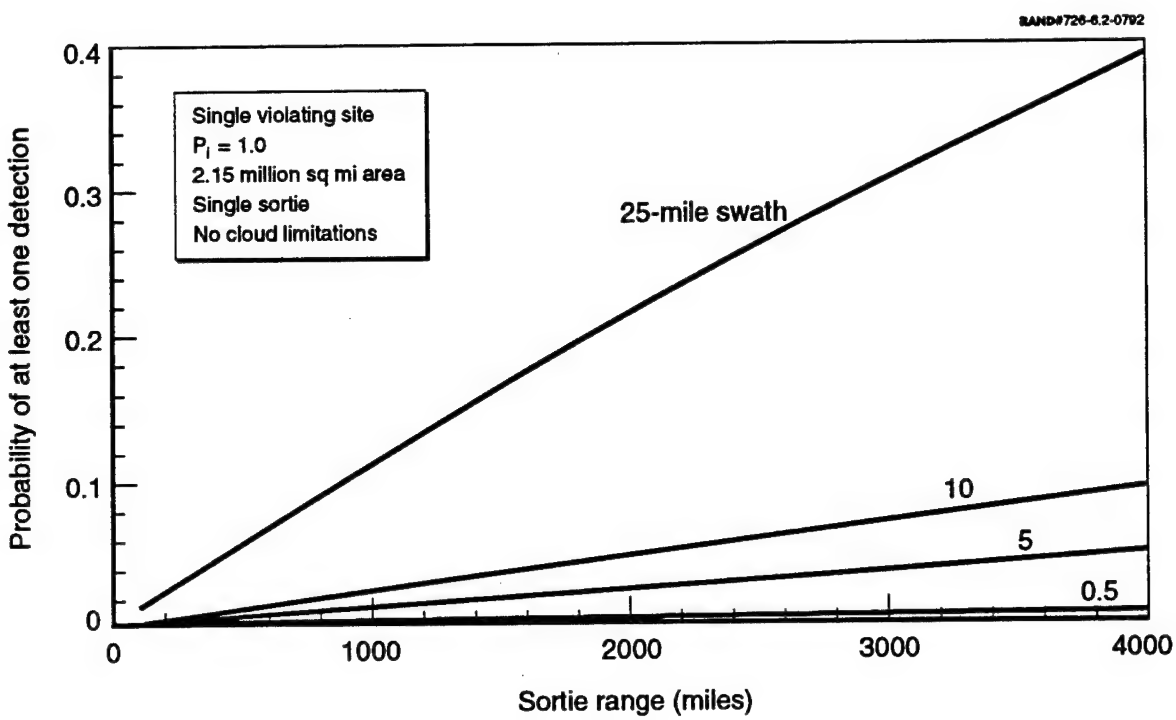

Figure 6.2—Aerial Inspection of Undeclared Sites: Wide-Area Search with SAR by Sortie Range

[2]See Appendix B, part E.

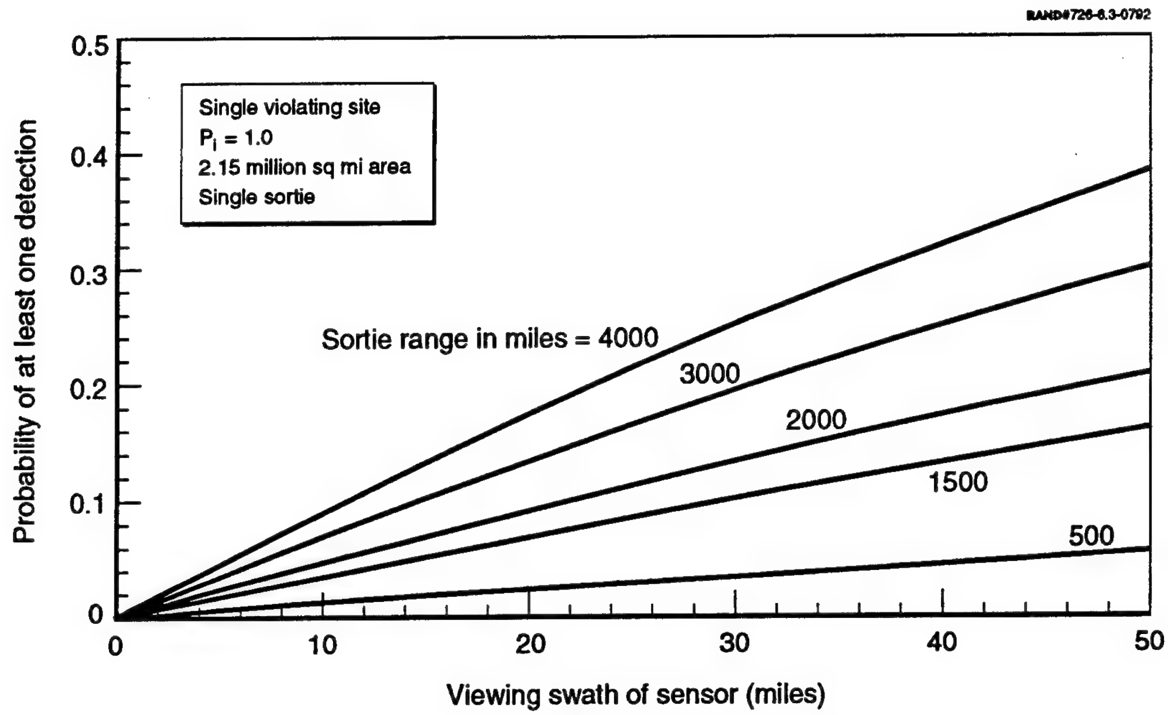

Figure 6.3—Aerial Inspection of Undeclared Sites: Wide-Area Search with SAR by Sensor Swath

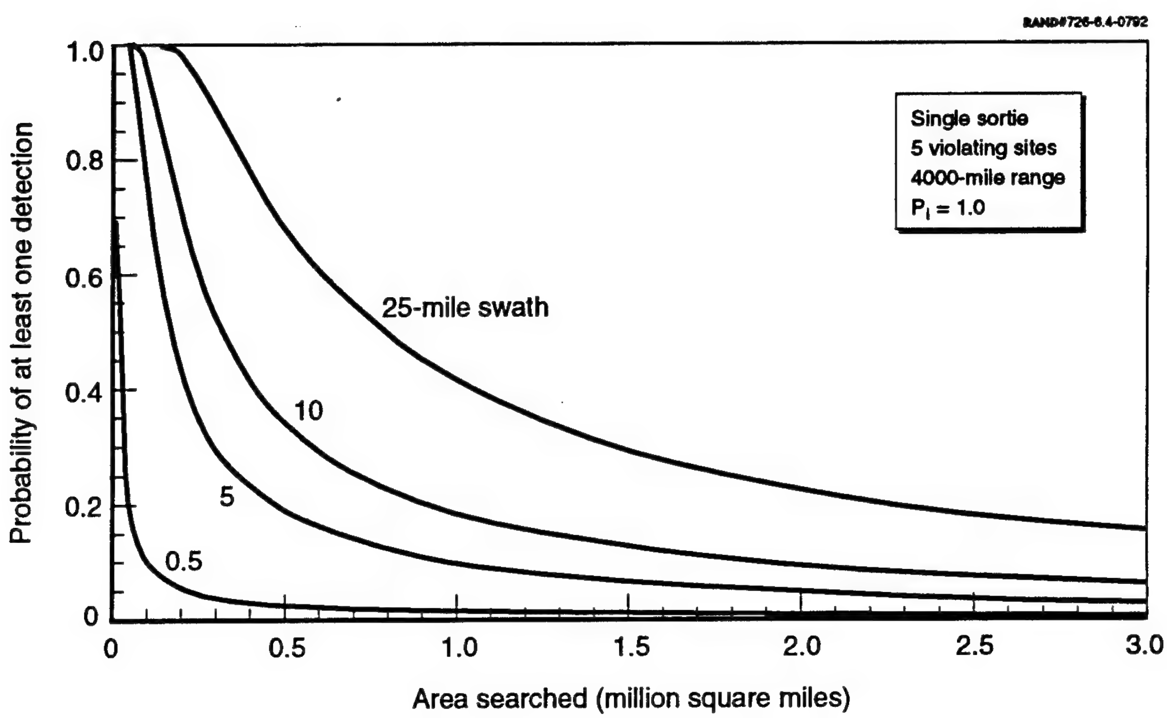

Figure 6.4—Aerial Inspection of Undeclared Sites: Wide-Area Search with SAR by Area Searched

Figures 6.5 and 6.6 each give the probability[3] of detecting new suspect sites by aerial inspection using sorties of 4000 miles and a 10-mile swath width, when there are five or ten new suspect sites, as a function of the number of sorties flown. Figures 6.7 through 6.10 give additional results for detecting new suspect sites, where the sortie ranges, sensor swath width, and number of suspect sites are varied.

A difficult issue to evaluate is the trade-off between an all-weather synthetic aperture radar system with a limited capacity to scan the ground and a photographic or IR system that is limited by weather. If half of the ground sites were obscured by cloud cover to photo or IR imaging, then, to a first approximation, only half of its search area potential would be realized. This would suggest that 70 to 80 percent cloud cover would be necessary for the SAR area coverage, with 10-ft resolution, to match or exceed the area covered by photography.

Tables 6.2 and 6.3 illustrate the potential utility of aerial wide-area search to detect new USSR deployments of militarily significant tank quantities within the European portion of the USSR. The tables give the number of wide-area search sorties required to detect with a probability of 0.9 at least one of the new sites, where P_i, the conditional probability of detection given an overflown, changed site, is assumed to be a function of the unit size at that site. Table 6.2 assumes a 4000-mile sortie range, or about an 8-hour flight. Table 6.3 assumes a 1500-mile sortie range, or about a 3-hour flight. Calculations in both tables assume the use of a SAR with a 10-mile swath width.

Table 6.4 shows the number of sorties required to detect at least one new suspect site assuming a 1500-mile sortie range and a 25-mile swath width, which represents coverage by a photographic or IR system constrained half of the time by cloud cover. Table 6.5 gives comparable results as in Table 6.4, assuming a 500-mile (one-hour flight time) for wide-area search imaging.

It appears from these data that for aerial inspection to be effective in locating new suspect sites, it must be able to image about 2 million square miles annually. If aerial inspections are limited to a few tens of inspections per year with an hour or two of flight, then they may be best employed as an adjunct to OSI, or in response to cuing by NTM to rapidly investigate suspect sites.

An alternative approach to finding new suspect sites is to employ wide-area search when flying between declared sites. The area searched would depend not only on sortie range and imaging swath width but also on the average amount of time spent imaging each

[3]See Appendix B, part E.

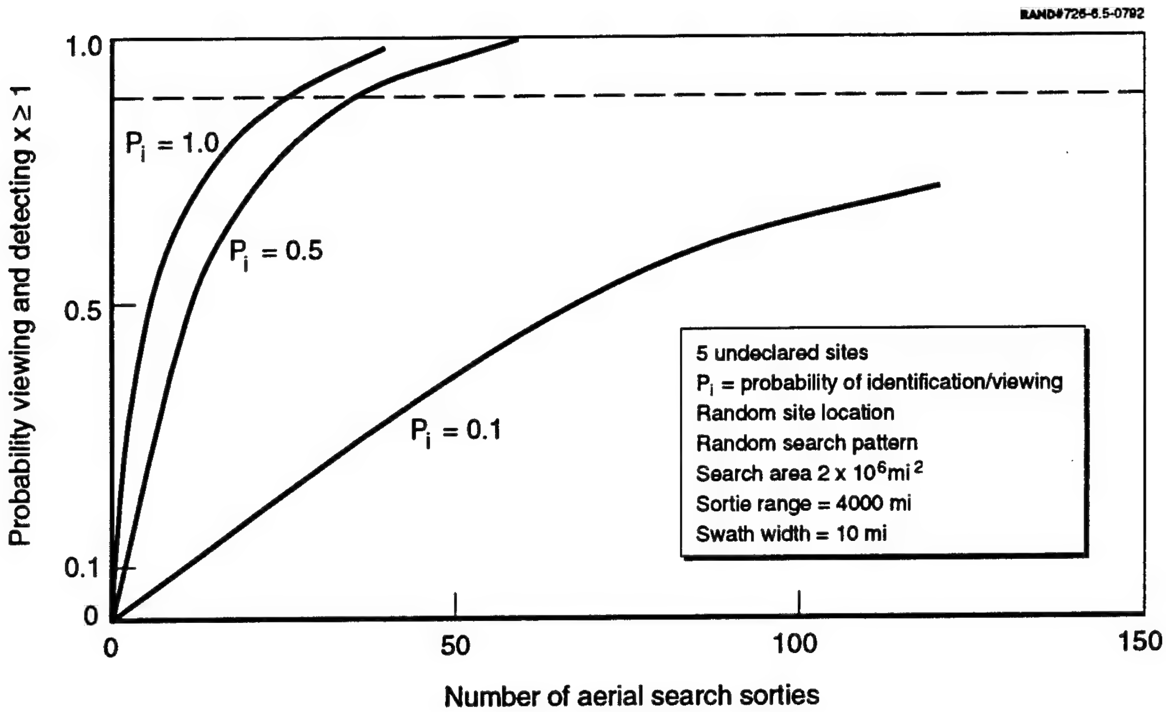

Figure 6.5—Aerial Sorties Required to Detect at Least One of Five New Undeclared/Suspect Sites

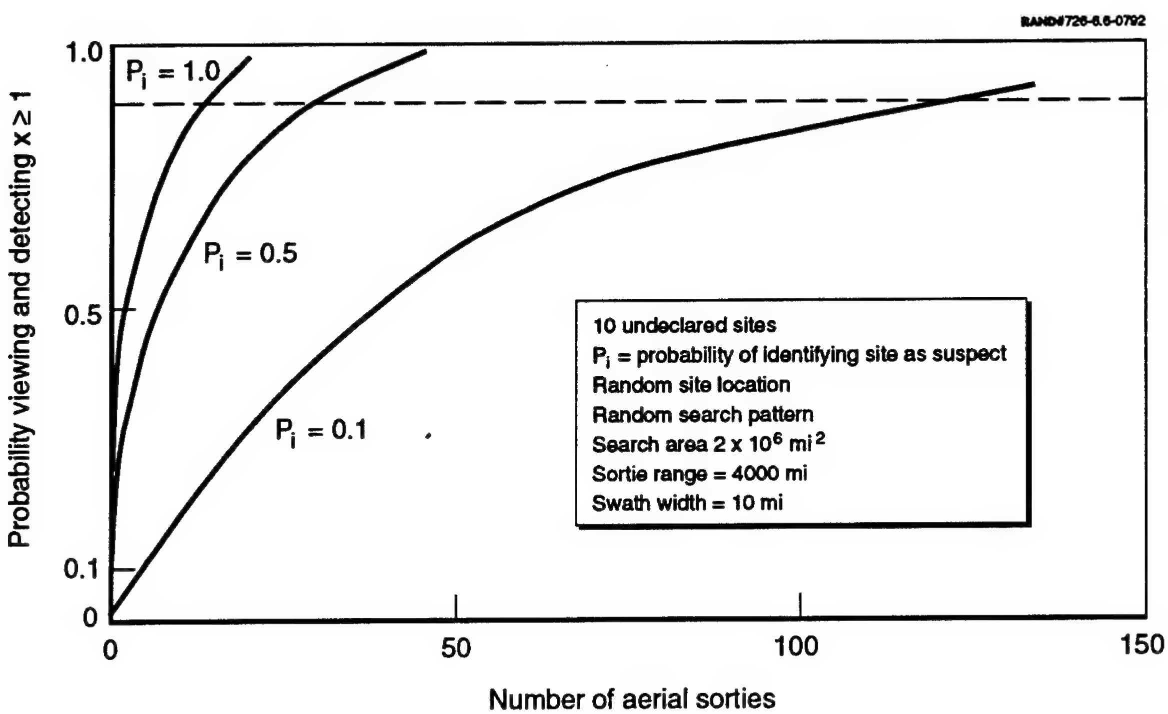

Figure 6.6—Aerial Sorties Required to Detect at Least One of Ten New Undeclared/Suspect Sites

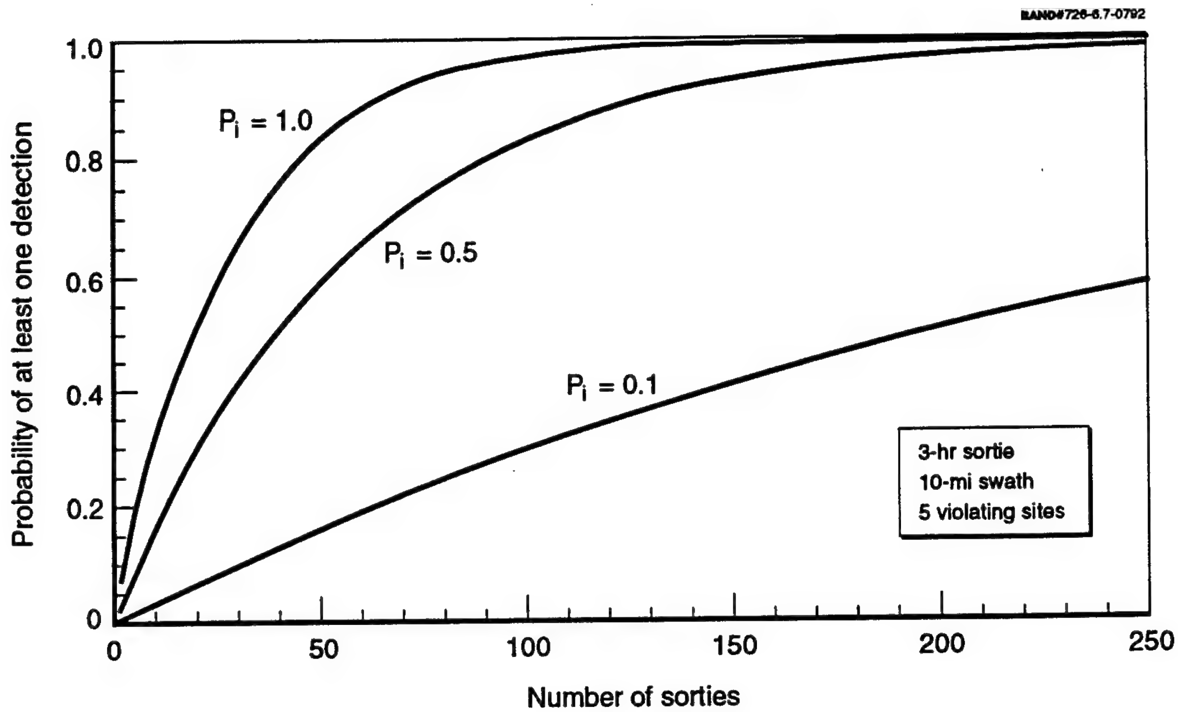

Figure 6.7—Aerial Inspection of Undeclared Sites: Wide-Area Search with SAR (3-hr Sortie, 10-mi Swath)

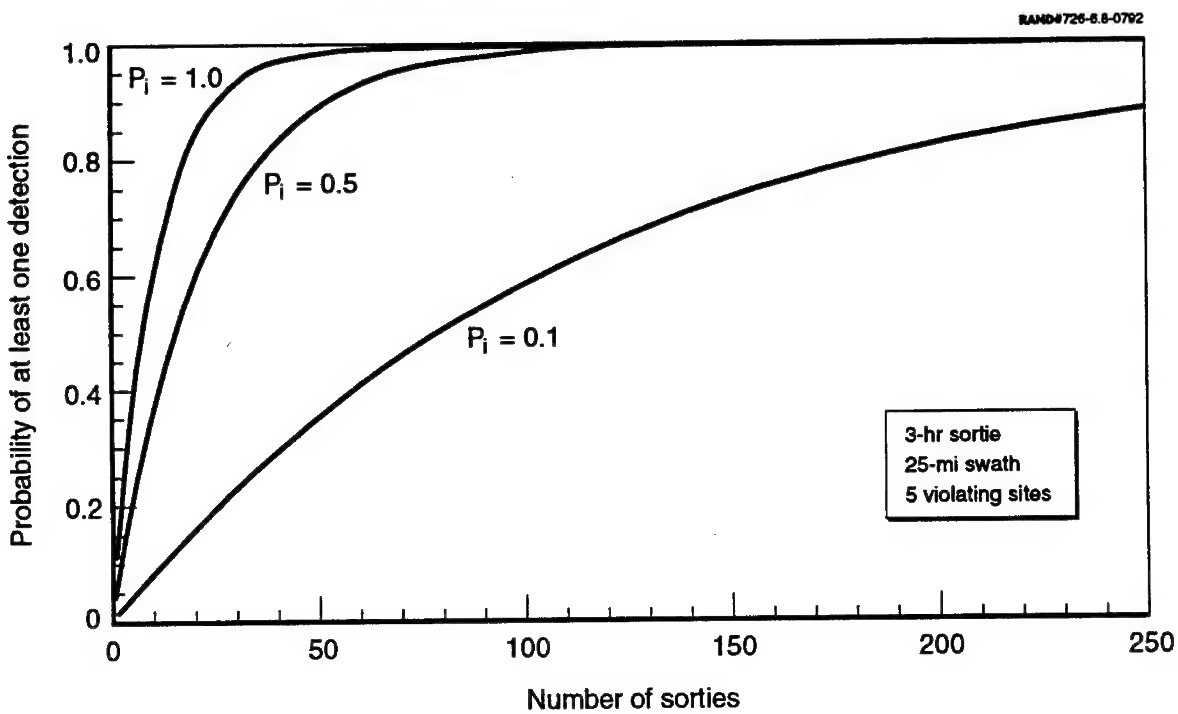

Figure 6.8—Aerial Inspection of Undeclared Sites: Wide-Area Search with SAR (3-hr Sortie, 25-mi Swath)

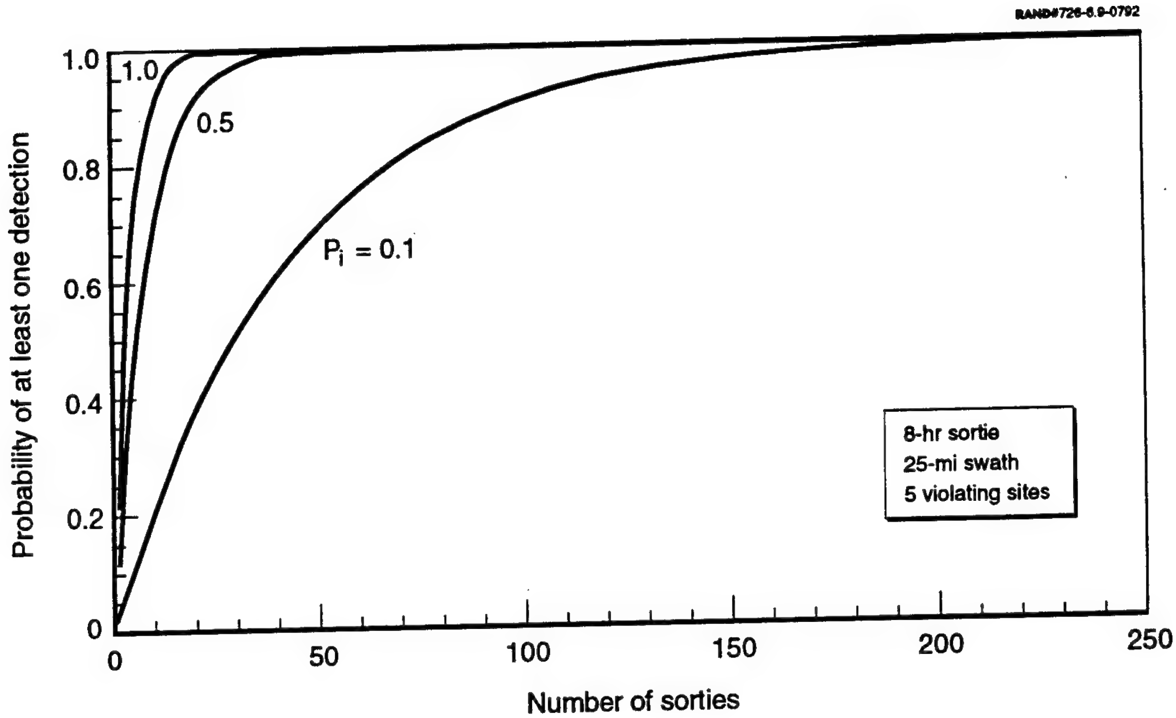

Figure 6.9—Aerial Inspection of Undeclared Sites: Wide-Area Search with SAR (8-hr Sortie, 25-mi Swath)

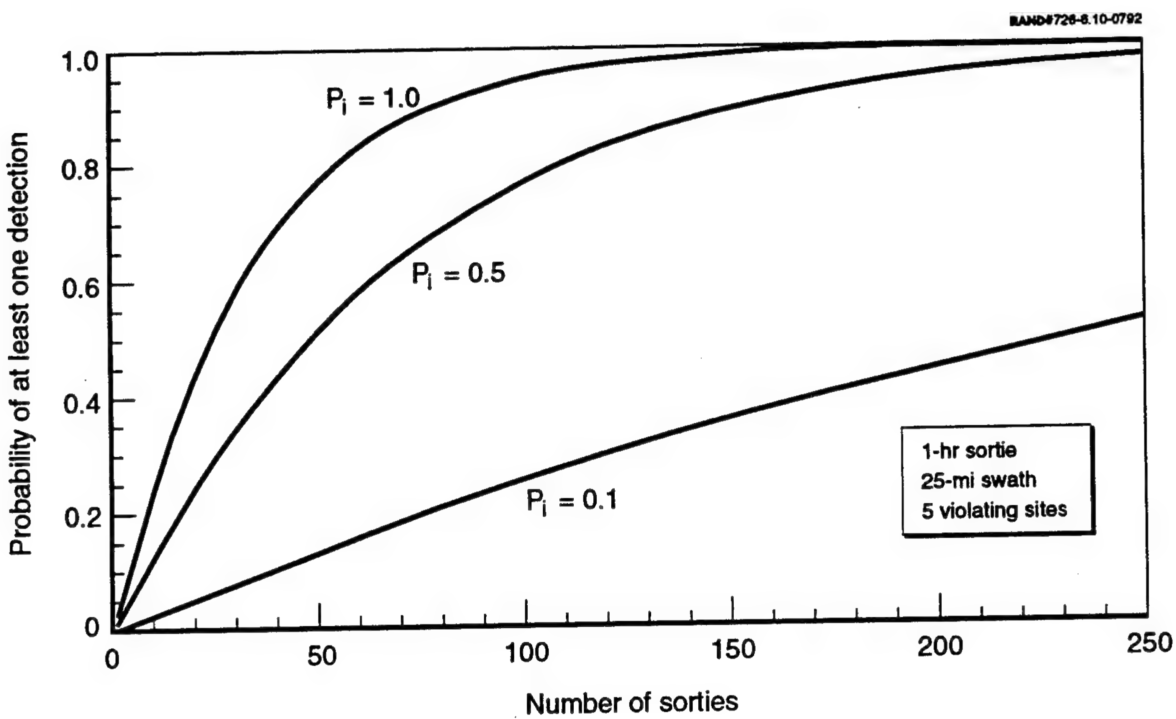

Figure 6.10—Aerial Inspection of Undeclared Sites: Wide-Area Search with SAR (1-hr Sortie, 25-mi Swath)

Table 6.2

Number of Sorties to Detect New Suspect Sites (4000-mi sortie range)

Type	No. of Tanks	P_i	Number of Undeclared Suspect Sites					
			1	3	5	10	20	40
Battalion	40	0.1	1250	412	255	124	62	31
Lt regiment	80	0.5	247	82	50	25	12	6
Hvy regiment	150	0.5	247	82	50	25	12	6
Division	320	1.0	123	41	25	12	6	3

NOTES: 10-mile swath
4000-mile sortie range
90% confidence of detecting at least one undeclared site

Table 6.3

Number of Sorties to Detect New Suspect Sites (1500-mi sortie range)

Type	No. of Tanks	P_i	Number of Undeclared Suspect Sites					
			1	3	5	10	20	40
Battalion	40	0.1	3300	1100	660	330	165	83
Lt regiment	80	0.5	660	220	132	66	33	17
Hvy regiment	150	0.5	660	220	132	66	33	17
Division	320	1.0	329	110	66	33	17	8

NOTES: 10-mile swath
1500-mile sortie range
90% confidence of detecting at least one undeclared site

Table 6.4

Number of Sorties to Detect New Suspect Sites (25-mi swath, 1500-mi sortie range)

Type	No. of Tanks	P_i	Number of Undeclared Suspect Sites					
			1	3	5	10	20	40
Battalion	40	0.1	1319	440	264	132	66	33
Lt regiment	80	0.5	363	88	53	27	13	7
Hvy regiment	150	0.5	363	88	53	27	13	7
Division	320	1.0	131	44	27	13	7	3

NOTES: 25-mile swath
1500-mile sortie range
90% confidence of detecting at least one undeclared site

Table 6.5

Number of Sorties to Detect New Suspect Sites (500-mi sortie range)

Type	No. of Tanks	P_i	Number of Undeclared Suspect Sites 1	3	5	10	20	40
Battalion	40	0.1	3960	1320	792	396	198	99
Lt regiment	80	0.5	791	264	159	80	40	20
Hvy regiment	150	0.5	791	264	159	80	40	20
Division	320	1.0	395	132	79	40	20	10

NOTES: 25-mile swath
500-mile sortie range
90% confidence of detecting at least one undeclared site

declared site, which would reduce the time available to conduct wide-area search. There are difficulties with this approach. First, unless the imaging swath is fairly wide, at least 10 miles, or other flight paths between declared sites are allowed, areas may be omitted from possible aerial observation. Second, when traversing straight paths between declared sites, areas near the declared sites will be imaged much more frequently. The assumptions of randomness are less fitting in this analysis. Also, areas unlikely to be imaged may become attractive for building new sites.

With the above limitations in mind, Figures 6.11 and 6.12 give the probability of at least one detection of a suspect site, when flying between suspect sites, when five suspect sites are uniformly distributed west of the Ural Mountains, as a function of the average imaging dwell time per declared site and for varying numbers of sorties, where the sortie range are 4000 and 1500 miles, respectively, with a 10-mile imaging swath width.

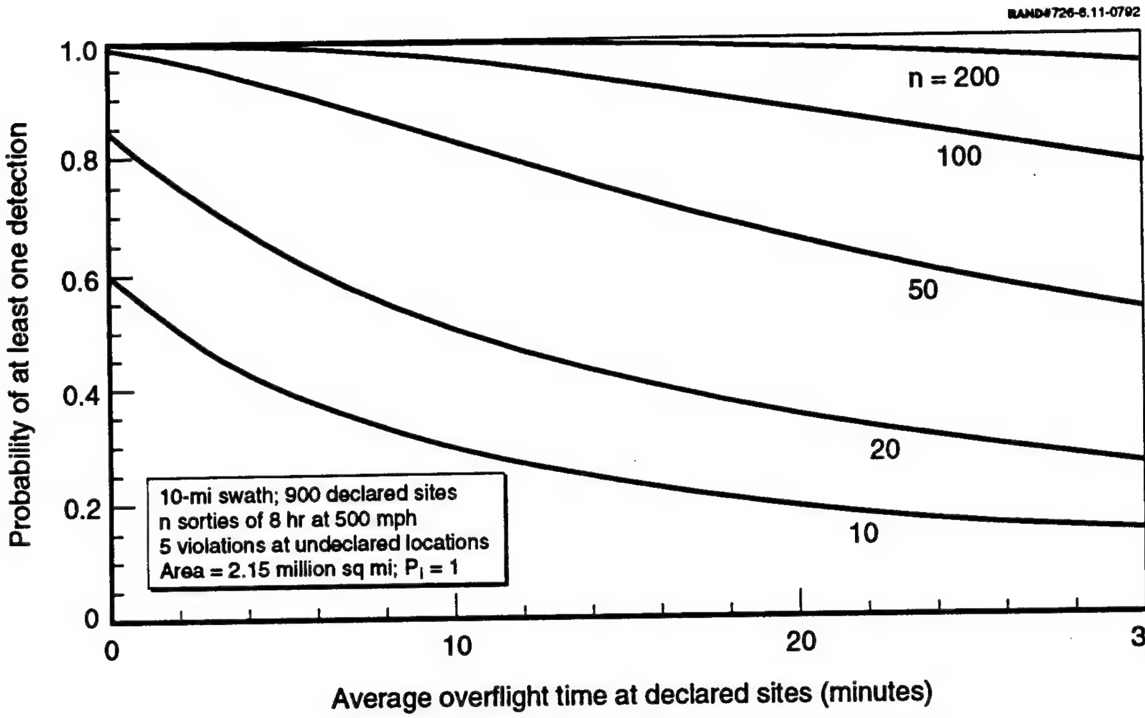

Figure 6.11—Aerial Search for Undeclared Sites: SAR Is Turned on Between Overflights of Declared Sites (8-hr Sortie)

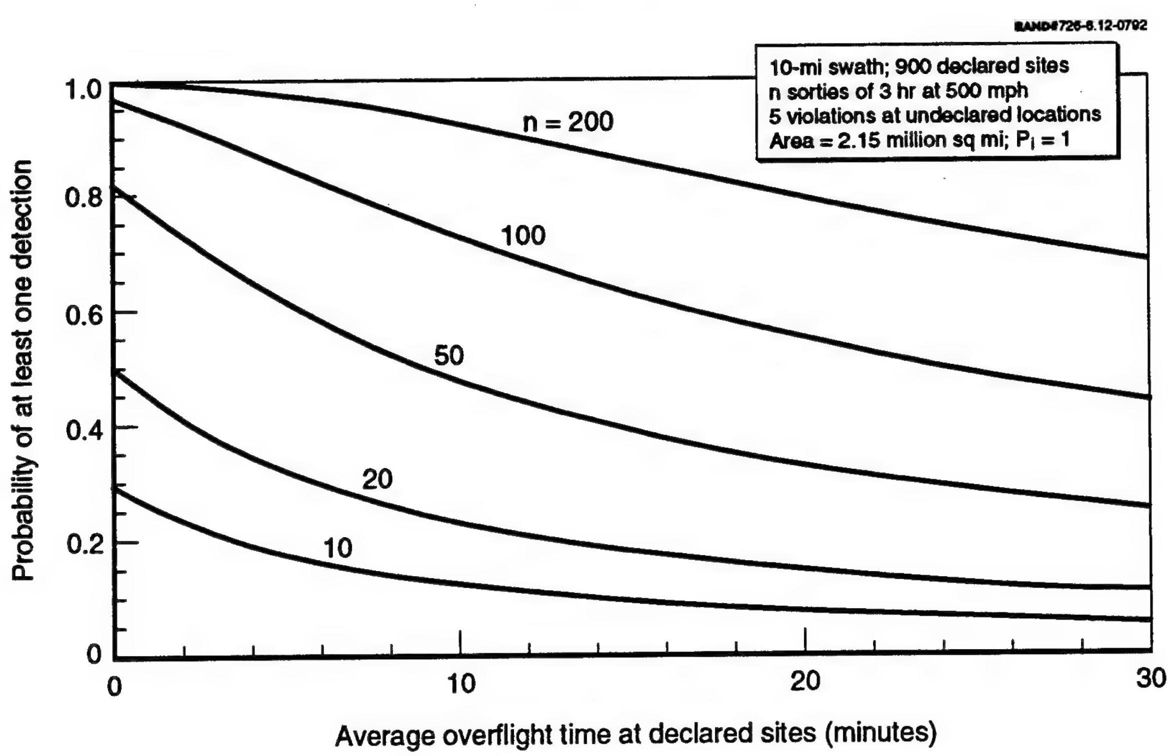

Figure 6.12—Aerial Search for Undeclared Sites: SAR Is Turned on Between Overflights of Declared Sites (3-hr Sortie)

7. AN INTEGRATED INSPECTION REGIME FOR THE RESIDUAL TREATY PERIOD

Priorities for achieving treaty objectives must be established before devising an integrated inspection regime for the residual treaty period. Should emphasis be on counting TLE accurately with OSI? Or should accurate counting be secondary to simply locating TLE at declared sites by serial number? How many aerial inspections should be employed to locate new suspect sites versus detecting new deployments or facilities at declared sites?

The emphasis given to one or another monitoring objective will depend on what OSI or aerial inspections can do, and how well. If there are severe limits on numbers of inspections allowed, or on the flight time of aerial inspection sorties, it could significantly change how an inspection regime is constructed to achieve the monitoring objectives. If aerial sorties are short-ranged, and few in number, their only reasonable use may be to overfly and image new suspect sites when cued by other means.

Some kinds of treaty violations or site changes can be detected by either OSI or aerial inspection, whereas other kinds of infractions, violations, or force changes may be detected only by OSI. (Table 3.1 in Section 3 lists infractions or changes that are judged to be detectable by OSI and aerial inspection.) For those changes and violations that can be detected by both aerial and OSI, the probability of detection will be greater than the calculated probability of detection by either OSI or aerial inspection alone. There are inspection requirements that may be accomplished only by OSI. Aerial inspections could detect suspect sites, but in principle can be replaced by OSI. Aerial detection can, however, be cost-effective. The following illustrations show how assumptions about the behavior of the inspected party, choices for critical values of militarily significant quantities, time to detection of violations and changes, and treaty-imposed performance limitations on aerial inspections could affect the size, type, and effectiveness of inspection regimes.

An inspection regime must be designed to be reasonably insensitive to the manner in which changes or violations might be pursued by the inspected party. Thus, an inspection regime should have a balanced ability to detect major violations at declared as well as at undeclared sites, at many sites or at a few sites, and to ensure that all declared sites have an equal opportunity to be selected for OSI or aerial inspection. Treaty-limited tanks could be located at declared tank sites or at undeclared sites. The effectiveness of the inspection regime will depend on how well it can perform over the spectrum of possible cheating scenarios. The treaty, however, may inhibit monitoring of sensitive sites for circumventions.

The building blocks for an inspection regime used in these illustrations are defined in Table 7.1. Table 7.2 lists the assumed treaty conditions and inspection performance capabilities. It was assumed for this illustration that in a residual monitoring period the former USSR did not reduce the number of its TLE ground sites, keeping ground unit forces at about half of current strength. Table 7.3 gives four sets of monitoring objectives with different values for militarily significant quantities (MSQ) of tanks, different time requirements for detection of MSQ and other violations, and whether the additional tanks are deployed over 100 sites or 10 sites. Scenarios 1 and 3 assume excess deployments of 1000 and 2000 tanks, respectively, over 100 sites. Scenarios 2 and 4 have 1000 and 2000 excess tanks deployed over only 10 sites. A scenario 1 objective for OSI is to detect a Soviet deployment of 1000 additional tanks by ensuring the detection of at least one of the 100 deployment sites, each with 10 extra tanks, within four weeks of their deployment. Scenarios 2 and 4 have as their OSI objectives detecting at least one of the 10 sites, with either 100 or 200 tanks, within 40 weeks.

Table 7.1

CFE Inspection Regime Building Blocks

- OSI estimation of TLE at declared TLE sites
- OSI inspection at TLE and non-TLE sites for infractions, etc.
- Aerial inspection of declared sites
- Aerial search for suspect sites

Table 7.2

Treaty and Other Assumptions

- Cooperative TLE monitoring measures: site limits, tagging, serial numbers
- No constraint on number of OSI per site
- Aerial inspection of declared site with 3–5 ft resolution
- All-weather aerial inspection capability using SAR, 10-mile swath, 10-ft resolution
- Random inspection of all declared sites
- Aerial inspection sortie range = 4000 miles or 1500 miles
- 250 tank sites; 250 airfields; 400 non-TLE sites
- $P_i = 1.0$ for OSI

Table 7.3

Illustrative Scenarios

Assumptions and Objectives	Scenario 1	2	3	4
Number of sites	250	250	250	250
MSQ tanks	1000	1000	2000	2000
Changes in tank sites	100	10	100	10
P_D changes in tank sites (OSI)	0.9	0.9	0.9	0.9
Time to detect tanks, weeks	4	40	8	40
Number of aircraft	250	250	250	250
MSQ aircraft	1360	1360	1360	1360
Changes in aircraft sites	100	100	100	100
P_D changes in aircraft sites (OSI)	0.9	0.9	0.9	0.9
Time to detect aircraft, weeks	8	8	8	8
P_D non-TLE violation (OSI)	0.9	0.9	0.9	0.9
Time to detect non-TLE violation	8	8	8	8
P_D change in tank sites (air)	0.9	0.9	0.9	0.9
Time to P_D = 0.9 change in sites (air)	4	4	4	4
Time to P_D = 0.9 suspect sites (air)	8	8	8	8

The large disparity in time to detection among scenarios stems from the difficulty in being able to randomly select any of the ten offending sites for an on-site inspection from a population of 900 sites on a timely basis. Criteria for detecting new military units with TLE at declared sites, at nondeclared sites, or for TLE aircraft at declared air bases are also listed for each scenario.

Using the results and assumptions described in the two previous sections, Table 7.4 lists the numbers of OSI and aerial inspections required to achieve the designated objectives for scenario 1 as listed in Table 7.3. Assuming there is agreement to either set limits on the number of TLE allowed at each site or call for individual TLE identification that will allow a discrete violation at a site to be detected, a total of 205 annual OSI would be required to satisfy scenario 1 objectives. If such cooperative measures were not in place, up to 390 annual OSI would be required to estimate the size of the tank population to determine whether there was compliance and to ensure that militarily significant circumventions did not exist.

Table 7.4

Inspections Required for Scenario 1 (distribution at 100 sites)

Inspection	To Estimate 1000 Tanks	To Detect 1000 Tanks Within 4 Weeks	To Detect 1360 Aircraft Within 8 Weeks
OSI tanks	390	55	NA
OSI aircraft		55	55
OSI other non-TLE		95	NA
Total OSI		205	55
Aerial (declared sites)		110	110

Inspection	To Detect 5% of Sites in Violation	To Detect 2000 Suspect Sites Within 12 Weeks
OSI tanks	55	
OSI aircraft	55	
OSI other non-TLE	95	
Total OSI	205	

Table 7.5 summarizes for each scenario the annual numbers of OSI and aerial inspections required to satisfy the objectives for the scenarios listed in Table 7.3. Between 200 and 250 annual OSI are estimated to be required across the spectrum of scenarios if supportive or cooperative inspection measures are implemented, whereas between 100 and 150 annual aerial inspections are deemed appropriate if a 4000-mile sortie range can be realized. If no special measures exist to help differentiate among individual TLE, then statistical sampling methods are used to estimate TLE populations, increasing the number of annual OSI needed. Other sets of monitoring objectives can be used to devise inspection regimes that accentuate different monitoring priorities.

Table 7.5

Inspections Required for Scenarios 1–4

Inspection	Scenario 1	2	3	4
OSI: estimated tank numbers				
Cooperative measures	205	240	110	240
Noncooperative measures	540	?	125	?
Aerial sorties: declared sites				
4000-mile range	110	145	45	75
1500-mile range	295	340	120	200
Aerial sorties: suspect sites				
4000-mile range	NA	100	NA	45
1500-mile range	NA	270	NA	115

The requirements for OSI and aerial inspection listed in Table 7.3 do not take into account the increased detection probability when both methods are capable of detecting the same event. If OSI and aerial inspections can both detect the same events, the probability of detecting those events will be greater than indicated by the OSI or aerial inspections alone.

Aerial inspections cannot be totally substituted for OSI. Some kinds of treaty circumventions and force changes cannot be detected by aerial inspections. For scenario 1, 205 annual OSI were also required to detect non-TLE infractions. In scenarios 1 and 3, the ten tanks per site assumed for the illegally deployed forces were considered to be too small for the detection capability of a 10-ft resolution SAR postulated for the aerial search for new suspect sites.

In principle, illegal TLE deployments could occur at fewer than ten sites, making the timely detection by OSI or aerial inspection even more difficult. When the number of declared TLE sites containing excess TLE is small compared with the total number of TLE sites, there may be difficulties in using traditional stratified sampling methods to detect TLE population increases. With only a few of the 900 declared sites containing increased TLE, much larger samples will be required to detect the increases with high levels of confidence.

The United States will be a major participant in monitoring the CFE Treaty, although it may be limited by agreement among the members of NATO and the treaty conditions. How well the United States can do on its own in ensuring Soviet compliance will depend not only on its participation in CFE monitoring but on its NTM as well. If the United States wishes to achieve specific monitoring objectives, it can negotiate its extra participation with other NATO members.

Typically, if the United States is limited to some less than desirable fraction of the inspections, it can compensate by reducing the level of confidence with which it can detect what it believes is militarily significant, it can increase the number of TLE deemed militarily significant, or it can accept a delay in the time that circumventions or changes are detected. More likely, the government will integrate its CFE monitoring activities with its NTM.

8. CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

This study has used assumed data, assorted analytic models, and illustrative calculations. Useful inferences, therefore, must be drawn with care. This section describes some general conclusions that are not sensitive to the detailed data.

CFE I negotiations for a monitoring regime may be long completed when this Note is published and recommendations made here may therefore be moot; they may, however, be considered for application to CFE II. The responsibility for monitoring of CFE I, and eventually CFE II, will be a NATO affair with all member nations participating. Recommendations proposed here are predicated on fulfilling potential overall NATO interests as they relate to U.S. interests. Other NATO nations' interests in monitoring former WTO forces have not been considered here.

Recommendations, particularly those for aerial inspection, are based on the assumption that the CFE monitoring regime should be self-sufficient to the extent possible. This approach may not be considered the most cost-effective for the United States, but it could represent the wishes of other NATO members.

CONCLUSIONS

A CFE monitoring regime and its implementation can be developed in a multitude of ways. There is likely no unique cost-effective answer as to how a regime should be constructed. An answer will come from trading off and balancing between competing political and military objectives, within political and economic constraints. OSI is likely to be more thorough and less susceptible to large-scale deception than aerial inspection. Aerial inspection may, however, cover many sites per sortie and yield other advantages, such as increasing the number of sites for which deceptive methods may have to simultaneously be implemented.

There could be an important synergism between on-site and aerial inspections. An aerial inspection can either precede or follow an on-site inspection within a short period of time. Such actions could make attempts at deception more difficult. Moreover, aerial inspection may be a more effective way to rapidly detect the introduction of large TLE units at declared sites.

If SAR is the aerial inspection on-board sensor, with limited resolution, then small increases in TLE forces at declared or undeclared sites may be difficult to detect. OSI may be

the preferred way to detect small force increases widely spread among the declared sites. This synergism between OSI and aerial inspection should be evaluated in greater operational detail.

The success in monitoring the former Soviet Union's adherence to TLE limits—that is, detecting the deployment of MSQ of TLE quickly, within a month or two—will in part hinge on whether there is regularity in the numbers of TLE at similar Soviet units (battalions or regiments) or, alternatively, on whether all TLE are identifiable (ID) by serial number or by unique tagging. Regularity could be imposed by the treaty requiring that no site have more than a fixed number of TLE at any time. Alternatively, TLE can have unique identification numbers or tags allowing illicit TLE to be detected by OSI. Without either TLE regularity or identification, either hundreds more OSI will be required or the time to detect new MSQ of TLE will have to be increased.

Whether or not there are constraints or TLE ID, the effectiveness of TLE monitoring will be increased with an aerial inspection adjunct capable of detecting large numbers of TLE when deployed at very few sites. Depending on sortie flight range or time, 5 to 50 sites may be imaged by an aerial inspection, giving a potentially high rate of inspection, albeit with lower resolution.

If the deployment of a MSQ of TLE (1000 to 2000 tanks) is to be detected among a population of 12,000 TLE, then the fewer the declared sites the 12,000 are deployed at the better. Fewer OSI are required, all other things being equal, the smaller the number of declared sites the TLE population is deployed at.

To validate the initial exchange data base about 200–250 OSI will be required, allowing an estimate of the TLE population to 1 percent assuming a virtual stand down of TLE forces or individual TLE identification. Without TLE identification, or with TLE irregularity among like units, nearly all the declared TLE sites may require inspection to ensure a 5 percent TLE accuracy in the number of TLE located in the European portion of the former USSR. Moreover, the 200–250 OSI will ensure, with high confidence, the detection of data exchange discrepancies if those discrepancies should exist at over 5 percent of the 1200 declared Soviet sites. Data exchange discrepancies would consist of mislabeling units (identifying a regiment as a battalion, or a tank regiment as a motorized rifle regiment, or the wrong command and control organization for a site, or the wrong level of site readiness).

The appropriate role for aerial inspection in the validation of data exchange is to image all declared former Soviet sites to verify that sites not inspected by OSI are what they are claimed to be, and to ensure there is a basis for comparison with future aerial

inspections. Depending on what sensor is used to image declared sites and other operational details, between 300 and 500 aerial inspection hours would be required to image 1200 declared sites located in Central Europe and in the former USSR. If only 900 declared sites located in the European portion of the former USSR are imaged, then between 200 and 350 hours of aerial inspection are needed. The selection of a sensor for data base validation should reflect the objectives and requirements for aerial inspection in the post-ratification period.

RESIDUAL ERA MONITORING

With high regularity (treaty-imposed TLE limits at like units or with TLE ID such as serial number registration or tagging), 200–250 OSI annually at declared Soviet sites and 200–250 aerial inspections should be adequate to detect, with high confidence, 1000 to 2000 additional TLE within a period of four to six weeks of their deployment. Moreover, if other than TLE number changes are occurring, i.e., changes in readiness levels, organizational command and control structure, TLE qualitative improvements, etc., they will be detected with high confidence within eight weeks when 5 percent or more of the declared sites have undergone change.

With TLE number limits per site, or with TLE ID, the inspection process would be checking the number of TLE per site or determining by checking their ID whether they legally deployed. Without TLE ID or site limits, and where TLE regularity is not assured, the TLE monitoring process becomes one of sampling sites, counting TLE, and estimating the TLE population parameters to test the hypothesis that the true population size is less than some militarily significant value. To detect with high confidence 1000 to 2000 TLE within four to six weeks of their deployment, when there is great uncertainty and variability in the number of TLE deployed at sites, may require at least 500 annual OSI.

If there is a high degree of variability in the number of TLE at declared sites, for whatever reason, then 500 OSI annually may not be sufficient to detect increases of 1000–2000 TLE at declared sites with any confidence for at least several months. Such irregularity, however, could be an indication of difficulty and should raise concern.

Aerial inspections have the potential for the timely detection of large new units deployed at a few sites. The statements above of having high confidence for detecting new deployments of 1000 to 2000 TLE are predicated on the assumption that a Soviet division can readily be detected by aerial inspection. With a range of 4000 miles per sortie, and an average dwell time to image a site of 5 minutes, 100–125 annual sorties should with high confidence be able to detect the deployment of five new divisions within four weeks. If the

average dwell time at a site increases to 15 minutes, the annual number of aerial inspections required to detect five new divisions will double, or take eight weeks with 100–125 aerial inspections to give a high confidence of detection.

About 300 annual aerial inspections would be required to detect five new divisions deployed at new or nondeclared sites within four weeks of their deployment with high confidence. These results assume that a wide-area search is undertaken throughout the European part of the former USSR, employing a SAR with 10-ft resolution, essentially unconstrained by weather, and 4000-mile range per sortie. While the objective for the search would be to locate new suspect sites, declared sites could be inspected on a less regular basis during the wide-area search. The number of declared sites monitored in this way would vary from sortie to sortie.

The United States, once having established its priorities and objectives for CFE monitoring, can decide on the basis of the analyses presented how many OSI and aerial inspections it wishes to be able to perform annually, or conversely, to establish its monitoring objectives to be consistent with its negotiated annual inspection quota.

Alternatively, the quota of U.S. inspections could be used as a deterrent to wide-scale treaty violations by the former Soviet republics and as a confidence-building measure. Monitoring to deter CFE Treaty violations has not been expanded on in this Note. An underlying premise is the prospect of unacceptable cost, politically at least, of a detected circumvention. How this would translate to the monitoring requirements of the CFE Treaty is uncertain. If there is a high political cost for being found violating the CFE Treaty in a significant way, even a small likelihood of detection could deter such behavior.

Costs for being found in violation of the CFE Treaty can fluctuate and are a function of the degree of circumvention as well as of political factors whose importance could vary over time. This suggests that designing a monitoring system to deter may be equivalent, or nearly so, to designing a high-confidence monitoring system to detect significant treaty violations.

RECOMMENDATIONS

As noted above, the CFE negotiations were under way during the course of this study and were completed before the Note was published. Recommendations here to support those negotiations may also be useful in support of CFE II negotiations or other like arms control treaties.

Given the uncertainty of how organized and orderly OSI will be during the data exchange period, it was recommended that between 500 and 1000 OSI be available to NATO

to validate the data exchange by the former WTO. If all goes well, and there is ample cooperation between NATO members in accumulating and sharing consistent data and sufficient data to estimate TLE populations within a percent or two, and to validate other baseline exchange data, fewer than the maximum amount of inspections would be necessary. It is to guard against uncertainty that between 500 and 1000 OSI be available for validating the baseline data exchange, depending in part on what fraction of the inspections will be performed by the United States.

If aerial inspections are permitted, we propose that all declared former Soviet sites in the USSR be imaged by aerial inspection to validate their location and the types of units deployed there, to serve as a basis for comparing imaging from future aerial inspections. If aerial inspection is employed, we also recommend that a SAR with a resolution of between 3 and 5 ft be considered for that purpose, recognizing that if this proposal is adopted there may be the potential for an undesirable transfer of technology to the former USSR. In time, such capability will be available to the former USSR republics, but having the capability for aerial inspection almost anywhere, anytime in the ATTU region of the former USSR may make such a near-term technology loss acceptable. Moreover, a 3 to 5 ft resolution SAR could be the preferred sensor for aerial inspection in the post-baseline era.

We recommend that in the post-baseline era that 450 to 500 annual OSI be permitted for all of NATO. This could assure high-confidence detection of 1000 to 2000 tanks within four weeks of their being introduced to declared Soviet sites. It would also allow the United States 100–125 annual inspections with which to detect the deployment of an additional 4000 tanks to declared Soviet sites within six to eight weeks. It was recommended that NATO perform 125 to 150 aerial inspections of Soviet Europe annually, and that the United States perform a subset of 50 to 60 aerial inspections annually. It is assumed that the aerial inspection sortie range will be either 1500 miles with an average imaging dwell time at each site of 5 minutes or less, or about 4000 miles and about 15 minutes average imaging dwell time per site or less.

So that no declared site is unavailable at any time for aerial inspection, it is recommended that a SAR with 3 to 5 ft resolution be considered. Such system capability may not be commercially available for several years. If additional aerial sensors are eventually allowed, consideration should be given to employing IR to increase the difficulties of on-site deception.

A balanced monitoring regime should have the capability to detect the new deployment of TLE at nondeclared sites. Using SAR with 10-ft resolution, between 40 and 75 annual aerial wide-area search sorties should detect the deployment of 4000 TLE distributed

over 10 or more nondeclared sites located in Soviet Europe within four to eight weeks of their deployment with high confidence. It is conceivable that these wide searches can be coordinated with the aerial inspection of declared sites. Thus, the total number of aerial inspections for declared and undeclared sites will be far less than required for aerial inspections of declared sites plus what will be required for the wide-area search for suspect sites.

The selection of SAR with 10-ft resolution for wide-area search is predicated on the requirement to ensure that all areas of Soviet Europe are readily accessible for search. Otherwise those areas of Soviet Europe that experience months of continuing cloud cover might become preferred locations for new TLE deployments.

We recognize the utility of having TLE ID to assist in on-site monitoring; we recommend, therefore, that additional study be given to the cost and feasibility of using individual TLE serial numbers to identify legally deployed TLE. Moreover, with individual TLE ID, compliance to population limits could devolve into counting TLE by units rather than by individual TLE. Site inspections would still seek to find TLE not properly identified.

Appendix A

VALIDATION OF THE DATA BASE EXCHANGE

A. VALIDATING THE TLE POPULATION BY RANDOM SAMPLING OF THE TLE SITES

The random sample of size N required to estimate the average number of TLE, $\bar{x}$, per site within an accuracy of ϵ percent of the declared population average μ_o is given by

$$N = \left(\frac{t_p \sigma_x}{\epsilon\, \bar{x}}\right)^2, \quad \text{for small } \epsilon \text{ and large N}$$

where σ_x = TLE population standard deviation, and
P_c = level of confidence, defined by T distribution = t_p.

It is assumed that $\bar{x}$, is normally distributed with

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$

$$\sigma_x = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{N-1}}$$

B. ESTIMATING TLE POPULATION BY PROPORTIONATE STRATIFIED SAMPLING OF THE TLE SITES

The random sample of size N required to estimate the average number of TLE, $\bar{x}$, per site within an accuracy of ϵ percent of the declared population average μ_o is given by solving tentatively for N in the expression

$$\epsilon = \frac{t_p \sigma_{\bar{x}}}{\bar{x}}$$

where $\sigma_{\bar{x}}$ = TLE standard deviation of the population mean
P_c = level of confidence, defined by T distribution = t_p
N_T = number of sites with TLE

where $\sigma_{\bar{x}}^{2} = \frac{1}{N^2} \sum_{h}^{1} N_h^2 \frac{1 - f_h}{n_h} \hat{\sigma}_{hx}^2$ and

$$\hat{\sigma}_{hx}^2 = \frac{\sum_{i}^{N_h} (x_{hi} - \bar{x}_h)^2}{N_h - 1}$$

and $\sigma_{\bar{x}}^{2} = \frac{\sigma_x^2}{N}$

$$N_T = \Sigma N_h$$

$$f_h = \frac{n_h}{N_h}$$

where N_h = number of sites in the h^{th} stratum

n_h = number of samples selected from the h^{th} stratum

$\bar{x}_h$ = average number of TLE at a site in the h^{th} stratum

L = number of strata

and

$$\bar{x} = \frac{\sum_{h}^{L} N_h \bar{x}_h}{N},$$ which is assumed normally distributed.

In cases A and B, the data exchange TLE count will be accepted if the difference between the estimated mean value, $\bar{x}$, is not more than ϵ percent greater than the declared mean value μ_o. In each instance, the given μ_o will be rejected as the true mean value if $\bar{x}$ is more than ϵ percent greater than μ_o.

C. DETECTION OF DATA EXCHANGE ERRORS

The probability of inspecting and of detecting x sites with data errors with a sample of size N is given by the binomial distribution as

$$P_D(x) \cong (N)(P_v P_i)^x (1 - P_v P_i)^{N-x}$$

where P_v = probability of visiting a site with an error: percent of sites with data errors,

P_i = conditional probability that an error is detected at a visited site, and

N = number of sites inspected.

The probability of finding at least one site with an error is

$$P_D(x \leq 1) \cong 1 - (1 - P_v P_i)^N$$

The average number of sites visited where errors are detected is

$$E(x) = N\, P_v\, P_i$$

It is assumed that sites are selected for inspection at random. These equations assume sampling with replacement and are only approximate.

D. DETERMINING THE NUMBER OF AERIAL SORTIES REQUIRED TO INSPECT AND IMAGE ALL DECLARED SITES

$$N_s = \frac{T_s}{T_i + T_\Delta} = \text{approximate number of sites inspected for sortie}$$

where T_s = total sortie flight time
T_i = average time to image a declared site
T_Δ = average flight time between declared sites

and

$$T_\Delta = \sqrt{\frac{A_T}{N_T}} \cdot \frac{1}{V}$$

where A_T = area containing declared sites
N_T = total number of declared sites
V = average aircraft speed between sites

The indulging assumption is that the declared sites are informally distributed over an area A_T.

Appendix B

MONITORING TREATY COMPLIANCE IN THE RESIDUAL TREATY ERA

A. DETECTING CHANGES IN THE TLE POPULATION SIZE BY RANDOM SAMPLING OF THE DECLARED TLE SITE ASSUMING AN UNKNOWN AVERAGE NUMBER OF TLE PER SITE AND STANDARD DEVIATION

The random sample of size N required to ensure that if the true average number of TLE per site is μ_o, this hypothesis will be accepted with probability P_c, and if the true average number of TLE per site is μ_c, the hypothesis that μ_o is true will be rejected with probability P_c, where the standard deviation for the distribution functions is constant, then N is given by the T distribution for

$$P\left(\bar{x} + t_p \frac{\hat{\sigma}_{\bar{x}}}{\sqrt{N}} < \mu_c\right) = 1 - P_c$$

and for

$$P\left(\bar{x} - t_p \frac{\hat{\sigma}_x}{\sqrt{N}} > \mu_o\right) = 1 - P_c$$

where μ_o = declared average number of TLE per site
μ_c = critical average number of TLE per site

and where $\hat{\sigma} = \dfrac{\sum (x_i - \bar{x})^2}{N - 1}$

and

$D(\mu_c, \sigma_x)$ and $D(\mu_o, \sigma_x)$, which have equal standard deviation, are the population density functions for the TLE. For

$$\bar{x} \geq \frac{\mu_c - \mu_o}{2}$$

the hypothesis of μ_o being the true average will be rejected.

For

$$\bar{x} < \frac{\mu_c - \mu_o}{2}$$

the hypothesis that μ_o is the true average will be accepted. This test ensures that μ_o will be accepted, i.e., the TLE are within treaty limits, in all but $1 - P_c$ fraction of the time, when true, and accepted as true only $1 - P_c$ percent of the time when μ_c is true.

B. DETECTING CHANGES IN THE TLE POPULATION SIZE BY SIMPLE STRATIFIED RANDOM SAMPLING OF THE DECLARED TLE SITES

It is assumed that the sites can be clumped into distinct stratum, each stratum having a mean and standard deviation. The random sample size N required to assure a critical change in TLE population as above in A will be based on the T distribution for

$$P\left(\bar{x} + t_p \frac{\hat{\sigma}_x}{\sqrt{N-1}} < \mu_c\right) = 1 - P_c \text{ and}$$

$$P\left(\bar{x} + t_p \frac{\hat{\sigma}_x}{\sqrt{N-1}} > \mu_o\right) = 1 - P_c$$

where $$\hat{\sigma}_x = \sum_h^L N_h^2 \frac{1-f_h}{n_h} \hat{\sigma}_{hx}^2$$

$$\hat{\sigma}_{hx}^2 = \sum_i^{n_h} \frac{(x_{hi} - \bar{x}_h)^2}{N_h - 1}$$

$$f_h = \frac{n_h}{N_h}$$

and N_h = the number of sites in the h^{th} stratum

n_h = the number of samples selected in the h^{th} stratum

$\bar{x}$ = the average number of TLE at a site in the h^{th} stratum

L = number of stratum

and

$$\bar{x} = \frac{\sum_h^L N_h \bar{x}_h}{N}$$

$$N_T = \sum_h^L N_h$$

A value of

$$\bar{x} \geq \mu_o + t_p \frac{\sigma_x}{\sqrt{N-1}}$$

will reject μ_o as the average value of TLE per site. A value of

$$\bar{x} \leq \mu_c + t_p \frac{\sigma_x}{\sqrt{N-1}}$$

will reject μ_c as the real average value of TLE per site. In the earlier treatment of TLE estimation for the validation of the exchange data base, sample size was adjusted to account for the finite character of the sample space. It was also anticipated that the number of samples employed to validate the TLE population size would be large compared to the number of sites. In the residual treaty era, it is anticipated that population estimation will be ongoing but will require independent estimates to be made on a short-term basis, perhaps monthly. Thus, relatively small sample sizes will generally be used for estimating purposes. The adjustment for a finite sample population therefore was not considered necessary.

C. DETECTING TREATY VIOLATIONS, INFRACTIONS, AND QUALITATIVE AND OTHER CHANGES BY OSI

See Appendix A, part C, changing P_v = fraction of sites to violations, infractions, and qualitative and other changes.

D. DETECTING CERTAIN TREATY VIOLATIONS AND CHANGES BY AERIAL INSPECTION

The probability of detecting at least one site with a violation or change is given by a form of the binomial distribution

$$P_D = 1 - (1 - P_v P_i)^{n \times N_i}$$

where P_v = the percent of sites with a violation or change

P_i = conditional probability that a change or violation is detected

N_s = the number of randomly selected sites imaged per sortie

n = the number of sorties

where $N_s = \dfrac{T_s}{T_i + T_\Delta}$

T_s = sortie flight time

T_i = average time to image a declared site

T_Δ = average flight time between sites

$$T_\Delta \sqrt{\frac{A_T}{N_T}} \cdot \frac{1}{V}$$

A_T = area containing declared site

N_T = number of declared sites

V = average aircraft speed

E. DETECTING A NEW SUSPECT SITE BY WIDE-AREA AIRCRAFT SEARCH

The probability of detection of at least one new suspect site is given by

$$P_D = 1 - \left[1 - \frac{A_s}{A_T} \cdot P_I\right]^{m \times n}$$

where A_s = area searched

A_T = total area subject to search

P_I = conditional probability that a suspect site will be detected

m = the number of actual suspect sites informally distributed over A_T

n = the number of search sorties

where $A_s = V\, T_s \times I_R$

V = aircraft speed

T_s = sortie time of flight

I_R = imaging ground range

F. DETECTING NEW SUSPECT SITES BY AREA SEARCH BETWEEN AERIAL INSPECTIONS OF DECLARED SITES

The probability of detection is the same as given in part E above, except for the term A_s, which will be defined as A_s',

where $A_s' = N_i T_\Delta V \times I_R$

and $$N_i = \frac{T_s}{T_i + T_\Delta}$$

$$A_s' = \frac{T_s T_\Delta V I_R}{T_I + T_\Delta}$$